SUMMARY OF
SIGNIFICANT
RESULTS IN—

Mineral resources
Water resources
Engineering geology
and hydrology
Regional geology
Principles and processes
Laboratory and
field methods
Topographic surveys
and mapping
Management of resources
on public lands
Investigations in
other countries

LISTS OF—

Investigations in
progress
Reports published
in fiscal year 1971
Cooperating agencies
Geological Survey offices

GEOLOGICAL SURVEY RESEARCH 1971

Chapter A

GEOLOGICAL SURVEY PROFESSIONAL PAPER 750–A

GEOLOGICAL SURVEY RESEARCH 1971

GEOLOGICAL SURVEY PROFESSIONAL PAPER 750

Significant results of investigations for fiscal year 1971, 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: 1971

UNITED STATES DEPARTMENT OF THE INTERIOR

ROGERS C. B. MORTON, Secretary

GEOLOGICAL SURVEY

V. E. McKelvey, Director

GEOLOGICAL SURVEY RESEARCH 1971

Chapter A

GEOLOGICAL SURVEY PROFESSIONAL PAPER 750–A

A summary of recent significant scientific and economic results accompanied by a list of publications released in fiscal year 1971, a list of geologic and hydrologic investigations in progress, and a report on the status of topographic mapping

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FOREWORD

"Geological Survey Research 1971," the 12th annual review of the economic and scientific work of the U.S. Geological Survey, consists of four chapters (A through D) of Professional Paper 750. Chapter A summarizes significant results, and the remaining chapters consist of collections of short technical papers. As in the past the purpose of the volume is to make available promptly to the public many of the highlights of Survey research and investigations.

Some, but not all, of the results summarized in chapter A are discussed in more detail in the short technical papers of chapters B through D, or in reports listed in "Publications in Fiscal Year 1971," beginning on page A295. The tables of contents for chapters B through D are listed on pages A289–A294 of this chapter.

Numerous Federal, State, county, and local agencies and other organizations and countries listed on pages A243–A248 made significant financial contributions to the results reported here. They are identified where appropriate in the short technical papers (chapters B–D), and in papers published cooperatively, but are not generally identified in the summary statements of chapter A. However, if a summary statement is the result of collaboration with a colleague from outside the Survey, the colleague's current organization (such as a university) is indicated in parentheses immediately following his name in the text.

The volume for next year, "Geological Survey Research 1972," will be published as chapters of Professional Paper 800. Previous volumes are listed below, with their series designations.

Geological Survey Research	Prof. Paper
1960	400
1961	424
1962	450
1963	475
1964	501
1965	525
1966	550
1967	575
1968	600
1969	650
1970	700

V. E. McKelvey
Director.

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REFERENCES

Text references are in three forms:

K. J. Englund (p. B13—B16)

Refers to a short paper published in a chapter of "Geological Survey Research 1971." The letter preceding the page numbers identifies the chapter. The tables of contents for the short-paper chapters are on p. A289–A294.

Page (r1273), Riley, and Haffty

Refers to a publication released in fiscal year 1971 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. A295. In the text, the prefix "r" replaces the first cipher of the acquisition numbers in the list. For publications with more than one author the acquisition number in the text follows the name of the first author.

Footnotes

Used for those publications that were released before or after fiscal year 1971, or that are in press, or whose authors are not members of the U.S. Geological Survey.

ABBREVIATIONS

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

A	angstrom units
A^3	cubic angstroms
acre-ft	acre-feet
B.P.	Before Present
b.y.	billion years
cal	calories
cfm	cubic feet per minute
cfs	cubic feet per second
cm	centimeters
cm^2	square centimeters
cm^3	cubic centimeters
cu ft	cubic feet
Eh	oxidation-reduction potential
emu	electromagnetic units
fpd	feet per day
fph	feet per hour
ft	feet
g	grams
gal	gallons
gpd	gallons per day
gpm	gallons per minute
ha	hectares
hfu	heat-flow units
hr	hours
in.	inches
kb	kilobars
kg	kilograms
kHz	kilohertz
kj	kilojoules
km	kilometers
km^2	square kilometers
km^3	cubic kilometers
kv	kilovolts
l.	liters
lb	pounds
m	meters
m^2	square meters
m^3	cubic meters
mg	milligrams
mgal	milligals
mgd	million gallons per day
mi	miles
min.	minutes
ml	milliliters
mm.	millimeters
mv	millivolts
Mwh	megawatt hours
m.y.	million years
μ	microns
μg	micrograms
μm	micrometers
μmhos	micromhos
μrad	microradians
n	neutrons
N	normal (concentration)
ng	nanograms
nm	nanometers
Oe	oersteds
ohm-m	ohm-meters
pH	pH (measure of hydrogen ion activity)
ppb	parts per billion
ppm	parts per million
sec	seconds
sq ft	square feet
sq mi	square miles
VLF	very low frequency
wt	weight
yr	years

ILLUSTRATIONS

RESOURCES INVESTIGATIONS

The U.S. Geological Survey carries out broad and highly diversified research programs to increase our understanding and to aid in our management of the mineral, energy, and water-resources potential of the land area of the United States and of the mineral resources of the adjacent continental margins. These programs play a vital role in furthering the Nation's development, as they provide basic information on the character, magnitude, location, and distribution of mineral and water resources, as well as on the principles and processes involved in their formation. This information provides a basis for many critical decisions and actions including location and development of mineral deposits, utilization of water resources, land management and use, urban planning and development, construction practices, and environmental and health problems. Highlights of the Geological Survey's investigations during fiscal year 1971 are summarized in this volume.

SPECIAL AND TOPICAL MINERAL-RESOURCE PROGRAMS

The mineral-resource programs of the Geological Survey focus on the solution of problems related to supplies of mineral raw materials and to the management of domestic resources. The programs comprise wide-ranging investigations pertaining to the origin, occurrence, and distribution of energy and nonenergy minerals and mineral raw materials in nature, to the development and improvement of mineral exploration concepts and techniques for locating new deposits of minerals, and to the evaluation of the known and potential mineral resources of the Nation. Important developments and highlights of these programs are summarized in this section; many other results are included in the section "Geological, Geophysical, and Mineral-Resource Studies."

Other special activities carried out by the Geological Survey in the mineral resource field include (1) mineral surveys of areas under consideration for inclusion in the National Wilderness Preservation System and (2) financial assistance, through the Office of Minerals Exploration, to private industry to stimulate exploration for certain mineral commodities.

BASE, FERROUS, AND PRECIOUS METALS

LEAD, ZINC, AND SILVER

Silver Cliff and Rosita area, Colorado

Surface geologic mapping, augmented by seismic and airborne magnetometer surveying, defines the specific boundaries of volcanic subsidence, locates principal magma ducts, and provides good estimates of depths of subsidence at both the Silver Cliff and Rosita volcanic centers, Custer and Rio Grande Counties, Colo. W. N. Sharp notes that such data provide excellent control for mineral exploration in the area. Halogen analyses of surface samples by J. S. Wahlberg show that chlorine, bromine, and iodine values are all relatively high over and around vent areas in the Silver Cliff volcanic subsidence block, and some of these halogen-rich areas correspond to old silver-mining sites. Sharp also found that galena and sphalerite from the Rosita area contain significant silver and that, without exception, the presence of copper in mineralized rocks signaled very high silver and significant gold values.

East Tintic district, Utah

Diamond drilling by the Kennecott Copper Corp. in the East Tintic district, Utah County, Utah, has confirmed the existence of a major concealed fault whose presence was inferred by H. T. Morris and W. M. Shepard in 1964.[1,2] This structure is a regional tear fault that apparently delimits or offsets the East Tintic and Midas thrust faults and terminates the Oquirrh-Tintic fold system. A probable exposure of this fault, which appears to be the strongest fault in the East Tintic district, has been recognized at West Mountain 15 mi northeast

[1] Morris, H. T., and Shepard W. M., 1964, Evidence for a concealed tear fault with large displacement in the central East Tintic Mountains, Utah, *in* Geological Survey Research 1964: U.S. Geol. Survey Prof. Paper 501-C, p. C19–C21.

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

of the district. It is of particular interest that the drill hole which cut the fault also cut 10 feet of mineralized and altered limestone containing significant quantities of argentiferous galena and sphalerite. Kennecott is currently making plans to explore this fault and the mineralized limestone beds by means of underground workings.

COPPER AND MOLYBDENUM

Composition of fluids in porphyry-type deposits

Microscopic study of fluid inclusions in samples from some 15 porphyry copper and porphyry molybdenum deposits in the Western United States by J. T. Nash has demonstrated a consistent relationship between fluid composition and wallrock alteration assemblages. Each deposit displays a core zone of potash feldspar–biotite alteration surrounded by a zone of argillic alteration. Fluids associated with the potash feldspar–biotite assemblage were highly saline (up to 40 weight percent) brines which, when trapped by mineral growth and cooled to present temperatures, formed fluid inclusions containing halite, hematite, and sometimes other daughter minerals in addition to liquid and vapor phases. Fluids associated with the surrounding argillic zone were much more dilute and were trapped as fluid inclusions which at room temperature contain only liquid and vapor phases. "Relict" fluid inclusions of the high-salinity type are commonly found well beyond the present limits of the potash feldspar–biotite core zone indicating that it was once more extensive and has subsequently been argillized by the more dilute fluids. Although of broad scope, this investigation indicates that the study of fluid inclusions may be a valuable adjunct to wallrock alteration studies because it provides a means of recognition of the former presence of an early brine, even though the potash feldspar and biotite may have been completely destroyed by subsequent superimposed argillic alteration. The recognition of such early brines in samples from leached outcroppings may be of economic significance.

Badlands area, South Dakota

Study of molybdenum occurrences in the Badlands area, Pennington County, S. Dak., by R. U. King and W. H. Raymond has shown that the molybdenum occurs as jordisite, ilsemannite, and as a yet unknown yellow powdery molybdenum oxide mineral that coats quartz sand grains. The molybdenum deposits are confined to the bottom 30 to 40 feet of the basal Chadron Formation of Oligocene age. The deposits are lenticular, discontinuous, and from about 1 inch to more than 10 feet thick. Contours drawn on the base of the Chadron Formation show a northeast-trending scour in the underlying Pierre Shale, and this scour is interpreted to have exerted major control on mineral deposition. The deposits contain from a few hundredths to more than 10 percent molybdenum, and although commercial deposits are not known to be present at this area, possibilities for the occurrence of economic deposits in this geologic environment are suggested.

IRON

The Lake Owens mafic complex in the southeastern part of the Medicine Bow Mountains, Albany County, Wyo., is a cup-shaped layered complex that is tilted to the northeast about 60° so that a cross section of distinctly layered rocks about 7 mi in length and 5 mi in width is exposed. Primary sedimentation features such as graded bedding, crossbedding, and channeling are well developed, and near the exposed top, large turbiditelike units, 8 to 20 feet thick, have coarse-grained (conglomeratic) bases and fine-grained tops. The rocks of the complex are olivine gabbro, leucotroctolite, norite, and anorthosite. These units alternate throughout the body, but an overall mafic to felsic transition can be recognized from base to exposed top of the body. Four magnetite-rich zones that range from massive discontinuous lenses to continuous layers (as much as 1 mi in length) of disseminated magnetite have been mapped by R. S. Houston on the eastern border of the body. The main concentrations of magnetite are along the margins of the complex, whereas near the base pyrrhotite and chalcopyrite have been identified in very small amounts.

PLATINUM

Platinum, palladium, and rhodium are concentrated in chromitite zones in the Stillwater Complex, Stillwater and Sweetgrass Counties, Mont., but individual samples show a wide variation in contents and ratios of these three platinum metals. N. J Page (r1273),[3] L. B. Riley, and Joseph Haffty found that values range from the limit of determination to 8 ppm Pt, 11 ppm Pd, and 1.7 ppm Rh. Stibiopalladinite, sperrylite, cooperite, platinum-iron alloy, and laurite are the only platinum mineral phases identified; they occur in the chromite as grains with an average diameter of 5μ. Chromium shows the strongest correlation with platinum metals, vanadium a moderate correlation, and nickel, cobalt, and copper little correlation. Platinum metals occur in the greatest amount where the oxidation ratio, $Fe^{+3}/(Fe^{+2}+Fe^{+3})$, of chromite is lowest. If chromite is a good petrogenetic indicator of conditions in the magma from which it crystallized, the close relation of platinum metals to the chromite suggests that lower oxidation conditions in the magma favored the concentration of platinum metals from the magma.

GOLD

Black Hills, S. Dak.

As a result of geochemical sampling in the northern Black Hills, Lawrence and Pennington Counties, S. Dak., R. W. Bayley has found, as did the old prospectors of the 1800's,

[3] See note opposite page A1 for explanation of reference notation.

that gold occurs in several specific geologic environments. The principal environment for gold is in lean iron-formation composed of chert-cummingtonite or chert-grunerite, the second is in quartz veins, and the third in massive ferruginous chert. Gold in the iron-formation is generally confined to plunging folds or internal drag folds. Plunging folds that affect the whole formation are most favorable for the occurrence of gold, and only a few such folds have proved to be barren. Most quartz veins are barren, especially those in graywacke, but those close to ore bodies or massive chert, or in black or graphitic slate commonly contain some gold. Massive cherts almost always contain a trace of gold, but of hundreds sampled none are of economic value. All gold-bearing areas are high in arsenic content, which may range up to 50,000 ppm.[4,5]

Haile-Brewer area, South Carolina

Airborne magnetometer data (U.S. Geological Survey, r0015) from parts of Kershaw and Lancaster Counties, S. C., indicate that numerous closely spaced Triassic dikes occur between two granite plutons. The dikes trend northwest through the hydrothermally altered Haile gold mine area. The possibility that this dike swarm was intruded into a preexisting shear zone suggests a northwest-trending structural control for the mineralized rock in this area. Henry Bell concludes that exploration along the dike swarm from the Haile mine might be more fruitful than northeast toward the Brewer gold mine as previously thought.

Grafton County, N. H.

J. P. D'Agostino recognizes two types of gold deposits in the lower Ammonoosuc Valley and Gardner Mountain areas, New Hampshire. In the lower Ammonoosuc Valley, auriferous vein quartz occurs in volcanic tuffs of the Middle Ordovician Ammonoosuc Volcanics. The quartz veins contain an average of 4.13 ppm gold and, according to an old report, as much as 107 ppm gold. The tuffs contain an average of 0.23 ppm gold, and where the tuffs are barren of gold, the quartz veins are also barren. D'Agostino concludes that the auriferous vein quartz was deposited by the lateral secretion of gold-enriched siliceous fluids derived from the adjacent auriferous tuffs during low-grade regional metamorphism. Thus, in metamorphic provinces similar zones of low-grade gold-bearing tuffs may contain potentially exploitable auriferous quartz veins.

Quartz veins at Gardner Mountain contain gold- and silver-bearing sulfides that D'Agostino postulates are genetically related to small gold- and silver-bearing massive sulfide deposits within the predominantly quartzose beds of the Lower and Middle Ordovician Albee Formation. The quartz veins contain 0.32 ppm gold and 27.0 ppm silver, and the massive sulfide deposits 0.67 ppm and 93.5 ppm, respectively. D'Agostino concludes that siliceous fluids caused by low-grade regional metamorphism mobilized some of the gold- and silver-bearing sulfides and deposited them with vein-quartz fill in adjacent tension fractures. In similar metamorphic terranes, the presence of gold- and silver-bearing sulfides in vein quartz may well indicate the occurrence of metamorphosed auriferous massive sulfides at depth.

Gold size distribution, Alaska placers

The amount of silt-size gold ($<62\mu$ or <250 mesh) in samples of placer deposits, of partly cleaned placer concentrates, of the suspended load in working placer sluices, and of tailings from Alaska has been determined by H. A. Tourtelot, R. F. Gantnier, and E. B. Ternes as part of a study of the size distribution of placer gold. The less-than-62μ fraction obtained by sieving was separated into 40μ, 20μ, 10μ, 5μ and $<5\mu$ fractions based on the settling times of gold spheres of these sizes. Gold analyses of each size fraction were made by atomic absorption methods. Samples of placer deposits being worked contained less than 0.1 ppm silt-size gold. They contain 10 to 50 percent silt-size material, and this size fraction commonly contains more than 0.1 ppm; one sample had more than 1 ppm. Nearly all samples that contain silt-size gold also contain larger gold which is still so small that scarcely any is ordinarily recovered by sluicing. The amount of silt-size gold in each of six placer concentrate samples supplied by operators ranged from a few to several hundred parts per million, but the actual value of this gold in any one sample was less than one cent. The average gold contents (dry weight) of the suspended load in each of three working sluices ranged from 0.05 to 1.8 ppm. Extrapolating these values to the total discharges of the sluices suggests losses ranging from \$0.60 to more than \$20 per hour of sluice operation. A clay ball from tailings contained 0.23 ppm silt-size gold.

Southwestern placer deposits

M. G. Johnson has compiled from the literature pertinent data on the widely distributed gold placer deposits in Arizona, New Mexico, Nevada, and Utah, and reports on each of the four States are being prepared for publication.[6,7,8,9] Most placers are small, local concentrations of gold in debris derived from nearby lode sources, and they have been mined by individuals using small-scale portable equipment. The most productive placers, however, occur in thick gravel deposits of

[4] Bayley, R. W., 1972, A preliminary report on the geology and gold deposits of the Rochford district, Black Hills, South Dakota: U.S. Geol. Survey Bull 1332-A. [In press]

[5] See note opposite page A1 for explanation of abbreviation.

[6] Johnson, M. G., 1972, Placer gold deposits of New Mexico: U.S. Geol. Survey Bull. 1348. [In press]

[7] —— 1972, Placer gold deposits of Arizona: U.S. Geol. Survey Bull. 1355. [In press]

[8] —— 1972, Placer gold deposits of Nevada: U.S. Geol. Survey Bull. 1356. [In press]

[9] —— 1972, Placer gold deposits of Utah: U.S. Geol. Survey Bull. 1357. [In press]

alluvial fans or well-defined gulches and are the product of long-term erosion of large gold vein deposits or pervasive systems of small gold-bearing veinlets. They have been mined by large-scale dredging or systematic sluicing and hydraulic operations.

Between 1774 and 1968, an estimated 564,000 ounces of gold was produced from 87 placer districts in Arizona. Twelve of these districts have produced greater than 10,000 ounces of placer gold. Many of the major placer districts are located in the Bradshaw Mountains in central Arizona where large systems of well-developed gold-quartz veins of Laramide and Precambrian ages were eroded and the free gold deposited with gravel in well-defined stream beds. Other major and minor placer districts are located in mountain ranges in the semiarid southwestern and southern parts of the State where the gold was derived from the erosion of numerous small veinlets and subsequently deposited in alluvial fans and small gulches.

There are 115 placer districts in Nevada from which an estimated 1,665,000 ounces of gold was recovered between 1849 and 1968. Thirteen districts produced more than 10,000 ounces of placer gold, and large gold-dredging operations active at various times between 1920 and 1959 in four districts–Gold Canyon, Battle Mountain, Manhattan, and Round Mountain–account for about 432,000 ounces of the total placer production of the State. Most of the placer gold found in Nevada was derived from vein and replacement deposits which have been successfully worked for gold and silver. Most formed during the Tertiary period and occur mainly in the western part of the State.

New Mexico has a total of 33 placer districts which are estimated to have produced 660,855 ounces of gold between 1828 and 1968. Seven of these have produced greater than 10,000 ounces of placer gold. Most placer deposits in New Mexico are derived from gold-bearing mineralized areas in Tertiary intrusive rocks and occur in gravels in alluvial fans, gulches, and rivers adjacent to the source. A few deposits are derived from gold-bearing Precambrian crystalline or Tertiary volcanic rocks. Most of the major placer districts were discovered and extensively worked between 1828 and 1880, but in later years large dredging operations were successful at the Moreno River placers between 1901 and 1903, and at Pinos Altos and Hillsboro between 1935 and 1942.

Eighteen placer districts in Utah produced an estimated 83,000 ounces of gold between 1864 and 1968. The most important placer district in the State is Bingham which produced over 75,000 ounces of placer gold, mostly between 1864 and 1900. The placers in the Bingham district occurred in thick gravel deposits in Bingham Canyon and tributary drainages and were derived mostly from lead-zinc-silver ores and oxidized copper ores of Oligocene age. Most of the other productive placers in Utah occur along the major river drainages in the eastern part of the State, where sporadic accumulations of flake gold in sand and gravel bars have been mined. Small placers are found associated with lode deposits in scattered areas throughout Utah.

LIGHT METALS AND INDUSTRIAL MINERALS

Beryl and columbite-tantalite

R. E. Van Alstine has found beryl and columbite-tantalite in coarse granitic pegmatite in the Pouncha Springs SE quadrangle, Chaffee County, Colo. A swarm of steeply dipping northeast-trending pegmatite dikes and sills, some as much as 50 feet thick, are localized in Precambrian metamorphic rocks along the southeast limb of an antiform. They are the external pegmatites of a large mass of gneissic quartz monzonite exposed less than a mile to the north[10] and are a southwest extension of the Turret pegmatite district described by Hanley and others.[11]

Beryl and columbite-tantalite are distributed erratically in intermediate zones of microcline-albite-quartz-muscovite pegmatite with accessory biotite, garnet, magnetite, hematite, and fluorite, and in cores of feldspar-quartz pegmatite. Blue-green beryl crystals generally are small, but some are as much as 4 feet long and a foot in diameter. The index of refraction of the ordinary ray, which varies inversely with the BeO content, is about 1.575, suggesting that the beryl contains about 13.5 percent BeO. The coarser material in the intermediate zone, where the beryl content is visually estimated to be about 1 percent, is best suited for hand sorting, and beryl could be recovered as a byproduct of mining feldspar and scrap mica.

Columbite-tantalite, confirmed by X-ray methods, occurs in thin plates, equant crystals, and lumps as much as 3 inches in diameter; it forms less than 0.01 percent, however, of any one pegmatite. Tests with a discriminating scintillometer showed that this mineral is strongly radioactive and contains uranium. The specific gravity was determined to be 6.0, suggesting a composition of about 35 percent Ta_2O_5.

Borates

The geologic setting of borate deposits in the Furnace Creek area, Inyo County, Calif., is shown by a new detailed map by J. F. McAllister (r1325) that presents some geologic bases for seeking concealed deposits and offers information to visitors in an accessible scenic part of Death Valley National Monument. The minable deposits of colemanite, ulexite, and probertite occur in the lower part of the nonmarine Furnace Creek Formation of Pliocene (Clarendonian and Hemphillian) age. A greater variety of borate minerals form minor lenses and veins more widely distributed in the formation. Complex aggregates of crystallized boric acid and fine-grained hydrous borates of calcium, sodium, and magnesium accumulate as efflorescences

[10] Van Alstine, R. E., 1969, Geology and mineral deposits of the Poncha Springs NE quadrangle, Chaffee County, Colorado: U.S. Geol. Survey Prof. Paper 626, pl. 1.

[11] Hanley, J. B., Heinrich, E. W., and Page, L. R., 1950, Pegmatite investigations in Colorado, Wyoming, and Utah, 1942–1944: U.S. Geol. Survey Prof. Paper 227, 125 p.

around favorably located outcrops of colemanite and priceite and in mine workings. The new borate mineral wardsmithite ($5CaO \cdot MgO \cdot 12B_2O_3 \cdot 30H_2O$) reported by R. C. Erd, J. F. McAllister, and A. C. Vlisidis,[12] is the fourth new mineral found in these aggregates. Different assemblages of 26 boron minerals, summarized in a brief text for the map of the area, maintain a leading position in borate mineralogy for the Furnace Creek area.

Clays

The clay deposits in Centre, Blair, Huntingdon, and Bedford Counties, Pa., according to J. W. Hosterman, contain light-gray to yellowish-gray silty to sandy clays composed of kaolinite with a little illite; quartz is virtually the only nonclay mineral. The largest deposits were formed in sink holes and caverns during weathering of silty dolomite in the Gatesburg Formation of Cambrian age and occur now as elliptical or lens-shaped bodies in the clayey silty sand residuum of the dolomite. Smaller clay deposits are formed by local weathering of cherty argillaceous limestone below calcareous sandstone of the Oriskany Formation of Devonian age. Most of the clay is used to make refractory products, but some is used in white portland cement.

Fluorspar

The Western States contain numerous fluorspar deposits with fluorite as the major mineral and varying amounts of quartz, chalcedony, barite, calcite, and iron- and manganese-oxide-bearing materials. The fluorspar deposits are generally epithermal in nature, and many are thought to be related to hot springs. For example, J. T. Nash examined fluid inclusions in samples of fluorite from Northgate, Colo., collected with R. G. Worl. The rarity of fluid inclusions in this locality, probably as a result of fibrous or columnar crystal growth, hampered study, but homogenization temperatures on samples from the fluorspar vein cluster in 4 groups—near 113°, 144°, 160°, and 177°C—approximately the same as determined by Steven.[13] Because of the small vapor fraction, metastable superheating was a problem in freezing runs, but several successful determinations indicate that salinities were near 0.2 wt percent NaCl equivalent. The fluids thus had the character of hot springs.

The wide range of habitat, nature of occurrences, and numerous mineralogical and elemental associations of the mineral fluorite lend credence to a hypothesis that the fluorspar deposits are surface or halo indications of related metallic mineralization. The hypothesis is based on the assumption that the fluorspar deposits and the minor and gangue occurrences of fluorite in and around metal deposits are manifestations of the same type of hydrothermal system. According to studies by Worl, some types of fluorite in hydrothermal deposits contain trace elements that may be indicative of the type of associated metal deposits. In deposits where the vein minerals are crystal aggregates, crystalline fluorite commonly contains trace amounts of metals; in banded or crustified deposits with single mineral layers, fibrous and columnar fluorite seldom contains traces of metals. Layers consisting of mixtures or intergrowths of fine-grained fluorite, chalcedony, and other minerals do contain trace metals. Such layers are usually thin, discontinuous, and generally were deposited following a brecciation stage.

[12] Erd, R. C., McAllister, J. F., and Vlisidis, A. C., 1970, Wardsmithite, $5CaO \cdot MgO \cdot 12B_2O_3 \cdot 30H_2O$, a new borate mineral from the Death Valley region, California: Am. Mineralogist, v. 55, p. 349–357.

[13] Steven, T. A., 1960, Geology and fluorspar deposits, Northgate district, Colorado: U.S. Geol. Survey Bull. 1082-F, p. 410.

Fuller's earth and bentonite

A review of fuller's earth and bentonite occurrences and mining in the States of South Carolina, Georgia, Alabama, and Florida was made by S. H. Patterson, as part of the continuing work by the Geological Survey in examining and reporting on the mineral resources of the Nation. According to this review, fuller's earth is widely distributed through rocks of Paleocene, Eocene, and Miocene age in these States. Bentonite occurs in formations of Late Cretaceous, Eocene, and Miocene age at scattered localities. Eleven plants processing fuller's earth were active in the Southeastern States in 1970, and two more were under construction; one bentonite plant was active. Fuller's earth has been produced at 13 other localities in the past, and bentonite was formerly produced at one place.

Peat

A buried deposit of peat from 1 to 14 feet thick was found on the Atlantic coast 7 or 8 mi southeast of Berlin, Md., during a study of the geohydrology of northeastern Worcester County, Md., by J. M. Weigle. The peat lies between 20 and 40 feet below sea level in Pleistocene deposits and underlies virtually the entire width of Assateague Island and more than half the width of adjoining Sinepuxent Bay. It is at least a mile wide at Assateague State Park. Available data suggest it may extend north-northeastward for several miles and may be contemporaneous with similar deposits at similar depths under Ocean City, Md.

Commercial quality reed-sedge peat was discovered in 41 of 52 deposits in St. Lawrence County, N.Y., investigated by C.C. Cameron. These deposits are estimated to contain nearly 13.8 million short tons of peat on an air-dried basis. The best grade peat in this region occurs in deposits scattered in partly buried preglacial valleys. The valleys extend along contacts of marble with gneiss and schist that form part of the Precambrian Grenville Series. Large deposits of reed-sedge peat were also discovered by Cameron in Washington County, Maine. The peat most suitable for commercial use in these deposits occurs in raised bogs (heaths) which have formed on marine clay adjacent to glacial end moraines. Reserves of peat on an air-dried basis in Washington County are estimated to be more than 19 million tons.

Rutile-ilmenite placers

Additional studies by J. P. Minard, E. R. Force, and G. W. Hayes, as a continuation of work previously reported,[14] indicate as expected that weight percentage of heavy minerals in terraces and bars along the Tye River decreases as downstream-transport distance increases from the rutile-ilmenite-bearing anorthosite at Roseland, Nelson, and Amherst Counties, Va. Although volume of fluvial deposits is small, percentage of heavy minerals is high in the first 6 to 8 mi downstream from Roseland. Percentages of heavy minerals in the large-volume terraces and bars along the James River, 30 mi downstream from Roseland, are high enough to be of interest, especially with the possibility of further concentrating processes. Floodwaters of hurricane Camille in 1969 concentrated heavy minerals locally on low terraces and bars, further upgrading the high values reported previously.

Salt

As the result of recent studies, A. J. Bodenlos (r1747) has concluded that fluctuations in the rate of solution by ground water have a major role in the apparent fluctuation of rate of movement of salt stocks in the Gulf Coast region. It previously has been thought that rock salt flowed upward intermittently and deformed the overlying strata as the movement took place. The results of these studies, however, suggest that appreciably more upward salt flow took place than is indicated by the deformation. No deformation of host rocks took place where the solution of the upper parts of salt stocks by ground water kept pace with salt movement. The caprocks on stocks are mainly accumulations of less soluble anhydrite which remain after the solution of salt. Caprocks 200 feet thick represent solution of thousands of feet of rock salt, and caprocks 1,000 feet thick represent solution of miles of rock salt.

Vermiculite

Thermal expansion and X-ray diffraction studies by A. L. Bush of vermiculite from Brazil, submitted by G. H. Goudarzi, yielded expansions that ranged from less than 10 to nearly 27 times, but diffraction patterns were far more characteristic of slightly altered biotite than of vermiculite. Additional investigations of 36 micas from widely separated localities, identified by the respective collectors as biotites, disclosed that half expanded more than 3 times, 10 expanded more than 6 times, and 6 expanded more than 10 times. X-ray diffractograms showing distinctive vermiculite patterns did not correlate directly with the most expansible micas. Laboratory study of an additional 42 specimens (including some "muscovites") generally tends to show the same lack of direct correlation.

Commonly it has been assumed that the thermal expansion of vermiculite results from the conversion of interlayer water molecules to steam which violently and nonuniformly disrupts the interlayer regions of the micaceous cell structure. A wide range of both regular and random stacking arrangements of biotite (or other micaceous minerals) and vermiculite are possible, but theoretically there should be a direct correlation between the total biotite, total vermiculite (regardless of the stacking arrangement), and the amount of thermal expansion. The apparent lack of this correlation suggests that another source of energy for expansion may be operative, such as the thermal release of OH^- ions from the mica layer to form water and then steam. It is not clear that the OH^- ions are present in adequate amount for the expansion, nor that the electromagnetic forces within the mica layer can be easily balanced to release the OH^-. The answers continue to be sought.

MINOR ELEMENTS

Niobium near Westcliffe, Colo.

Carbonatite dikes that cut pyroxenite and gabbro of the Gem Park Complex at Gem Park, about 11 mi northwest of Westcliffe, Custer and Fremont Counties, Colo., contain from <0.001 to 0.7 percent niobium in the form of pyrochlore. In addition to niobium, the dikes contain rare-earth, thorium, phosphorus, barium, and strontium minerals. Several niobium minerals—pyrochlore, fersmite, columbite, lueshite, and natroniobite—are also found in thin serpentine dikelets and vermiculite masses that occur in a small body of altered gabbro and pyroxenite in the central part of the complex. The niobium content of grab samples of these rocks ranges from <0.002 to >1.0 percent. Closely associated with the niobium are thorium and rare-earth minerals—thorianite and monazite. The alteration and mineralization may have resulted from emanations and solutions derived from an underlying carbonatite mass at unknown depth, as reported by R. L. Parker (r0653) and W. N. Sharp.

Rare yttrium mineral, South Platte area, Colorado

The third occurrence in the United States of the rare yttrium mineral thalenite was found by J. W. Adams and W. N. Sharp in pegmatite in the South Platte area, Jefferson County, Colo. The occurrence is of special interest because the thalenite and associated allanite appear to have been formed by the reaction of late-stage silicic fluids with yttrofluorite. Rare earths released by the destruction of yttrofluorite recombined with silica to form the two minerals, one containing dominantly yttrium subgroup elements and the other dominantly those of the cerium subgroup. Excess calcium and fluorine

[14] Herz, Norman, Valentine, L. B., and Iberall, E. R., 1970, Rutile and Ilmenite placer deposits Roseland District, Nelson and Amherst Counties, Virginia: U.S. Geol. Survey Bull. 1312-F, 19 p.

recombined to form normal fluorite which enclosed the two rare-earth minerals.

RADIOACTIVE MATERIALS

URANIUM

Large uranium deposits not likely south of the Beaver Rim, Gas Hills, Wyo.

In the Gas Hills uranium district the Wind River Formation, host rock for the ore deposits, dips to the southeast at a low angle. The Beaver Rim, a north-facing escarpment 400 to 500 feet high, crosses the southern part of the district. Ore bodies lie progressively deeper southward beneath the Beaver Rim, and the possibility of large ore bodies a long distance southward has been a major exploration tenet.

In a genetic model suggested by F. C. Armstrong (r2252), mineralizing solutions are postulated to have flowed northward through the Wind River Formation when the beds dipped northward. In so doing, the solutions leached and altered the Wind River. If this model is correct, it is unlikely that major ore bodies occur very far south of the Beaver Rim. Sparse small ore bodies, however, are expectable. They would be in areas of abundant mudstone where the mudstone protected them from the leaching action of the solutions during passage of the solutions northward.

Uranium possibilities in the San Ysidro area, New Mexico

Semiquantitative spectrographic analyses of samples of the Westwater Canyon and Jackpile Sandstone from the San Ysidro area indicate no unusual concentrations of trace elements that would suggest conditions favorable for uranium deposits, according to E. S. Santos. Trace-element composition of these units here closely resembles that in equivalent units in the Laguna and Ambrosia Lake area where they are barren of uranium, vanadium or molybdenum.

Secondary yellow uranium minerals were found by W. I. Finch one-half mile southwest of Cachana Spring near State Highway 44, near the base of the Entrada Sandstone.

Uraniferous volcanic ash and lacustrine limestone in eastern New Mexico and West Texas

All the small widely scattered Pleistocene Pearlette-like ash beds sampled by W. I. Finch and the late J. C. Wright in the southern High Plains are noticeably radioactive and contain 0.002 to 0.003 percent equivalent uranium. West of Channing in Hartley County, Tex., radioactive Pearlette-like ash overlies radioactive limestone beds of the Pleistocene Rita Blanca lake deposits. These limestone beds contain 0.007 to 0.008 percent uranium. The uniform distribution of uranium throughout both the ash and limestone beds suggests that the uranium is of syngenetic origin. Frye and others [15] show the location of about 45 other "Pearlette volcanic ash" deposits, most of which are in Oklahoma, Kansas, and Nebraska, that were not sampled for uranium but which may contain uranium in amounts similar to those reported here.

Theories of origin guide uranium-deposit exploration in Texas coastal plain

Continued exploration by uranium companies in the south Texas coastal plain has further confirmed the theories expressed by D. H. Eargle and A. D. Weeks concerning the factors of formation of the deposits: (1) presence of porous tuffaceous host rocks; (2) occurrence of arid-climate weathering that effected release of uranium to ground water; (3) presence of precipitants, especially H_2S, in the region; and (4) presence of fault and facies traps to retard flow of ground water.

Recent uranium finds are mostly on the western side of the old Rio Grande embayment in Duval and Webb Counties in porous rocks of middle to late Miocene and Pliocene age.

"Tilted bed" concept affords a broad guide to uranium exploration

A study was made by R. P. Fischer of the common geologic relations that seemingly influenced the localization of the principal domestic uranium mining districts and mineral belts and which might guide exploration for new districts and belts. The deposits studied are in sandstone beds that accumulated as stream-laid lenses interbedded with mudstone of flood-plain and lacustrine origin. These beds formed in intermontane basins, on broad alluvial fans or plains, or on coastal plains, all low-lying terranes with high water tables. The districts and belts are in beds that seem to have had a gentle dip, resulting from either initial stream gradient or slight tectonic tilting, and to have been localized in zones ranging from a few miles to a few tens of miles from the depositional or erosional edges of the host beds. In this geologic setting, ground water seeping downward by gravity would tend to be channeled in and move downdip along the more permeable beds—those that are now ore bearing—and any uranium carried by this water could precipitate where adequate reducing conditions were encountered. If the ground water contained only a little uranium, a long stable period of ground-water flow would be required to bring enough metal to make minable deposits. Areas of similar geologic environment and history, and containing sandstone beds of lithologic characteristics favorable for uranium deposits, can be recognized by geologic study; they might be fruitful for exploration. The known uranium deposits in sandstone occur in two rather distinct types—rolls and tabular bodies—and the optimum pattern of exploration drill holes

[15] Frye, J. C., Swineford, Ada, and Leonard, A. B., 1948, Correlation of Pleistocene deposits of the central Great Plains with the glacial section: Jour. Geology, v. 56, p. 501–525.

should be adjusted to the distribution and alteration habits of these two types of deposits.

THORIUM

M. H. Staatz [16] reports that the total rare-earth content of the thorium veins in the Lemhi Pass area, Idaho, is almost equal to the thorium content. The value of the contained rare earths, however, is at least several times that of the thorium. Although the rare earths and thorium commonly occur in the same minerals, the amount of one shows no relation to the amount of the other. Neodymium is the predominant rare earth in most of the veins. Europium, a rare earth used in making the red-producing phosphor in color television tubes, occurs in above-normal amounts in many veins.

ORGANIC FUELS

Environmentally significant trace fossils in the Raton coal field, New Mexico

Distinctive new suites of trace fossils found by J. O. Maberry and C. L. Pillmore in the Trinidad Sandstone (Cretaceous) in the Raton coal field in northern New Mexico include *Diplocraterion*, an unusual tubular vertical form that is ladder shaped in cross section, *Ophiomorpha*, *Aulichnites*, *Asterosoma*, *Teichichnus*, *Desmograpton*, and nonspecific tracks, trails, and burrows of a shallow-water epifauna that lived in the retreating Late Cretaceous sea. *Ophiomorpha*, the most abundant form, is common in the formation. *Diplocraterion*, found in abundance at two localities, is restricted to a zone 1 to 3 feet thick at the very top of the formation. This zone lies directly beneath the zone of the Raton coalbed at the base of the overlying Vermejo Formation (Cretaceous). Delicate trace fossils such as *Desmograpton* indicate gentle settling of fine particles that covered the structure in deep, quiet water. Burrows such as *Ophiomorpha* and *Diplocraterion* were constructed by domicile-building organisms that lived in areas of stronger current and high sedimentation rate and could build their burrows upward to keep pace with sedimentation. Because all individuals of the suite are bathymetrically significant, they are an aid to the interpretation of the paleoenvironment and may help guide future exploration for thick coal deposits in the Raton basin.

Coal in the Datil Mountain coal field, New Mexico

E. R. Landis and C. H. Maxwell confirmed the existence of potentially valuable coal in an area of about 20 sq mi in the Datil Mountain coal field, northeastern Catron County, N. Mex. The coal is probably subbituminous in rank and is in the basal part of the Cretaceous Crevasse Canyon Formation, just above the Gallup Sandstone. Coal beds at this horizon are generally less than 18 inches thick, but in the Datil Mountain field some are locally thicker than 3 feet. Detailed information on the persistence of the thicker beds is lacking.

Thickness trends and composition of the Pittsburgh coal bed, Pennsylvania

B. H. Kent reports that the Pittsburgh coal bed in southwestern Pennsylvania tends to be thin, low in sulfur content, and low in ash on the crests of low-amplitude northeast-trending anticlines and other structurally high areas, but that it is notably thick, high in sulfur, and high in ash in the trough of at least one major syncline. The folding is thought to be penecontemporaneous with deposition of the organic material that now is coal. The folds probably had at least slight topographic expression. Differences in the composition of the organic material deposited at different water depths on the resulting uneven surface might account for the present differences in the coal.

Aluminum redistributed during diagenesis of oil shale and tuffaceous rocks in the Green River Formation, Colorado

The redistribution of aluminum during the diagenesis of the tuffaceous rocks and oil shales in the Parachute Creek Member of the Green River Formation (Eocene age) in the Piceance Creek Basin, Rio Blanco County, Colo., is reflected by the variation in composition of the commonly occurring analcime, $Na(AlSi_2O_6)\cdot H_2O$, and its relation to the less common dawsonite, $NaAl(OH)_2CO_3$. Variation in the composition of analcime is easily studied by X-ray methods and expressed as an Si-Al ratio. Ideally constituted analcime has a Si-Al ratio of 2, but the analcime in all 100 samples examined by D. A. Brobst and J. D. Tucker has a Si-Al ratio greater than 2, generally between 2.5 and 2.7, indicating a low content of aluminum. Analcime in oil shales with dawsonite had even higher Si-Al ratios—2.7 to 3.0, indicating even lower aluminum content. In rocks with both analcime and dawsonite, the amount of one mineral varies inversely with the other. It is concluded from this study that the formation of dawsonite may consume so much of the available aluminum that only silicic analcime can form, or perhaps analcime is an aluminum donor during the formation of dawsonite.

Correlation of organically rich Cretaceous rocks extended in Colorado and Utah

The Sharon Springs Member of the Pierre Shale (Upper Cretaceous) heretofore unrecognized west of Kremmling, Colo., has been identified by J. R. Gill as a distinctive

[16] Staatz, M. H., 1971, Geology and description of the thorium-bearing veins, Lemhi Pass quadrangle, Idaho and Montana: U.S. Geol. Survey Prof. Paper 1351. [In press]

lithologic unit in the upper part of the Mancos Shale in the Book Cliffs area of western Colorado and eastern Utah. This thin weakly radioactive organically rich shale and bentonite unit has now been traced on the outcrop and in the subsurface over a 350,000-sq-mi area in the Western Interior region of the United States and into southern Canada.

Salinas Valley oil fields, California

Analysis of the distribution of stratigraphic units overlying the basement complex in the southern Salinas Valley area, Monterey and San Luis Obispo Counties, Calif., by D. L. Durham indicates that some structurally high areas on the surface of the basement complex were present in early Tertiary time and that others formed in latest Tertiary or Quaternary time. Distinction of the older from the younger features is of economic significance because all oil fields in the area are found over the older highs.

Tertiary rocks at the Elk Hills Petroleum Reserve, Calif.

Subsurface reference sections of Tertiary rocks at the Elk Hills Naval Petroleum Reserve No. 1 of the southern San Joaquin Valley, Kern County, Calif., have been established by W. L. Adkison in two drill holes which penetrated a section 6,600 feet thick of upper Oligocene and Miocene rocks. Stratigraphic nomenclature from exposures 15 to 50 mi to the northwest is used with the addition of a new member in the Monterey Shale. W. M. Berryman reports a reference section 3,700 feet thick of Pliocene rocks that includes the Etchegoin and San Joaquin Formations, whose type sections are inadequately described in incomplete exposures 60 to 80 mi to the north. The Etchegoin Formation in the Elk Hills section is subdivided into two new members.

Graben gas trap in the Wasatch Formation, Colorado

A northwest-trending graben, at least 8 mi long and 1 to 2 mi wide, found by G. N. Pipiringos on the northern periphery of the Piceance Creek basin, Rio Blanco County, Colo., appears to have influenced the course of the White River and the accumulation of natural gas in the northwestern and west-central parts of the White River City quadrangle. The graben is bounded by nearly vertical faults that trend about N. 55° W. The minimum vertical displacement measured in the Green River and Wasatch Formations (Eocene) is about 500 feet. The valley of the White River lies entirely in the graben, except along the west side of the quadrangle where the valley trends west for a mile before resuming its northwest trend. The northern boundary fault of the graben makes closure on the south flank of the White River dome. Wells drilled along the projected trace of the southern boundary fault on the western side of the quadrangle have yielded gas from the Wasatch Formation.

GEOTHERMAL ENERGY

Geochemistry of geothermal sources

Major progress, reported by D. E. White[17] at the United Nations Symposium on the development and utilization of geothermal resources, at Pisa in 1970, has been made in applying geochemistry to the discovery, evaluation, and exploration of geothermal resources. An essential first step by White (r1298), L. J. P. Muffler, and A. H. Truesdell was to recognize the contrasts between two fundamental types of systems, depending on dominance of liquid (hot-water systems) or vapor (vapor-dominated systems). Worldwide application of geochemistry has often failed in the past because volatile tracers (gases, boron, NH_3 and Hg) have been misapplied to the abundant hot-water systems. Water-soluble constituents of low volatility, such as SiO_2 and alkali metals, are much more useful in evaluating these hot-water systems.

Data from 27 explored hot-water systems, including Yellowstone examples studied by R. O. Fournier and Truesdell[18], are summarized by White, permitting comparison of spring-predicted temperatures and measured subsurface reservoir temperatures. The latter are most reliably predicted from SiO_2 contents of hot springs (superior to Na/K predictions in 17 of the 27 examples, but the Na-K ratio provides an excellent check for many systems and is actually superior in 10 of the 27). Near-surface dilution explains some of the SiO_2-based failures, but other failures, especially for reservoir temperatures about 200°C, are due to precipitation of SiO_2 en route to the surface. The greatest discrepancies in predicting temperatures from Na-K ratios generally involve waters that are relatively high in calcium and (or) bicarbonate content.

R. O. Fournier and A. H. Truesdell have extended the data reviewed by White on the relative merits of the silica and Na/K geothermometers by including many additional thermal waters where subsurface temperatures and compositions are known. Where silica indicates a temperature near but below about 175°C, and Na/K indicates a temperature above about 225°C, the Na/K is likely to give the better estimate. They also conclude that the Na-K ratio gives anomalously high estimated subsurface temperature where hot-spring waters are rich in calcium; an adequate understanding of the "calcium effect" is likely to improve the value of this geothermometer and will also clarify existing water-rock reactions in hydrothermal systems.

[17] White, D. E., 1970, Geochemistry applied to the discovery, evaluation, and exploitation of geothermal energy resources: United Nations Symposium on Development and Utilization of Geothermal Resources, Pisa, Italy, Sept. 1970, Rapporteur rept., sec. V. [Preprint]

[18] Fournier, R. O., and Truesdell, A. H., 1970, Chemical indicators of subsurface temperature applied to hot spring waters of Yellowstone National Park, Wyoming, U.S.A.: United Nations Symposium on Development and Utilization of Geothermal Resources, Pisa, Italy, Sept. 1970, Paper V/2. [Preprint]

Mercury in thermal fluids

Available data on the mercury contents of natural thermal and mineral fluids were summarized by D. E. White (r0674), M. E. Hinkle, and Ivan Barnes. Dilute warm and cold springs contain about the mercury content of unpolluted surface waters. Most high-temperature Yellowstone waters, closely associated with extensive Pleistocene volcanism, are only slightly enriched in mercury, having but 0.1 to 0.3 ppb. Some California thermal waters and nonthermal waters of appreciable salinity contain 1 to 3 ppb of mercury; sediments associated with some of these spring waters and gases contain 50 to 5,000 times the content of ordinary rocks, even where mercury minerals have not been observed. Mercury minerals are forming in at least five hot spring systems of the United States.

Petroleum and tarry residues of the Cymric oil field and the Abbott mercury mine contain the highest reported mercury contents of natural fluids; available analyses range from 300 to 500,000 ppb, or about 3 to 6 orders of magnitude above most thermal waters. Some but not all mercury deposits indicate involvement of petroleum and hydrocarbon gases. Data are inadequate on the mercury contents of hot-spring and volcanic gases, especially in view of the anomalous mercury contents of solid phases that indicate vapor transport. The origin and nature of the fluids that have formed most large mercury deposits are not yet clearly understood.

EXPLORATION RESEARCH

Areal geochemical studies

Coeur d'Alene district, Idaho.—Geochemical surveys have been conducted by U.S. Geological Survey personnel in a number of mining districts. G. B. Gott, J. M. Botbol, T. M. Billings, and A. P. Pierce[19,20] concluded that vertical zoning and metal associations may be useful in exploration in the Coeur d'Alene district, Idaho. Tellurium in low concentrations seems to have been driven beyond Pb, Zn, Cu, Ag, Cd, or Sb at the time that the ore minerals were emplaced. As a consequence tellurium is not present in detectable amounts in soils and rocks directly above shallow mineralized veins, but is present in surface materials where the mineralized veins are buried several hundreds of feet. It seems possible, therefore, that the presence of tellurium can be used to indicate the presence of deeply buried deposits, whereas silver can be used to indicate the presence of relatively shallow deposits.

A somewhat similar type of zoning is shown by the zinc-cadmium ratio in soil samples. Cadmium relative to zinc is enriched in a wide zone around a Cretaceous monzonite known as the South Gem stock. The cause of this phenomenon apparently was the fractionation of cadmium and zinc when sphalerite was formed under elevated temperatures at the time of the intrusion. Because sphalerites formed at high temperatures contain less cadmium than do those formed at low temperatures, a cadmium-rich halo tends to be formed around the heat source.

Zinc-cadmium fractionation is also found in the vein material and wallrock of the Lucky Friday mine. Sixty samples from all accessible levels in this mine from near the surface to a depth of 3,650 feet have an average zinc-cadmium ratio of 130:1 in samples of the vein material and 13:1 in samples of the wallrock. This tenfold enrichment of cadmium in the wallrock extends at least 150 feet on each side of the vein and increases the size of the exploration target many fold.

The zinc-antimony ratio of the soils seems to define the tetrahedrite deposits of the silver belt of the Coeur d'Alene district. Enriched antimony, relative to zinc, occurs in areas of known tetrahedrite deposits.

Tarryall district, Colorado.—In an electron-beam microprobe and spectrographic study of gold from the Tarryall district, Colorado, J. C. Antweiller and W. L. Campbell found that the silver content of placer gold differed from that of most of the nearby known sources of gold. One area peripheral to the Montgomery Gulch stock, however, was found to contain gold with a silver content similar to that of the placer gold. This area is thought to be the most likely source of the placer gold and a potential exploration target.

Empire district, Colorado.—A geochemical and statistical study by M. A. Chaffee of altered bedrock samples from the Empire district, Colorado, revealed correlatively high abundance and areal distribution between gold and the five elements tellurium, tin, bismuth, silver, and manganese. It is concluded that all five would be good pathfinder elements in the search for gold in the Empire district. Of the five, tellurium exhibited the most widespread anomalies and would be the best pathfinder element for reconnaissance work. Anomalies of the other four elements would be better suited for detailed investigations.

Montezuma district, Colorado.—G. J. Neuerburg, Theodore Botinelly, and K. E. Kulp[21] concluded that the distribution of hypogene iron oxides may be useful in prospecting the Montezuma district, central Colorado, for certain metals, some of which have not been mined or sought in the district. The depletion of accessory magnetite in fresh rocks of the Montezuma stock identifies sources of ore minerals for the pneumatolytic metals, locates probable areas of possible contact-pneumatolytic deposits, and, in the altered rocks of the stock, identifies rock through which hydrothermal ore fluids have passed. Specularite veins are located in structures

[19] Gott, G. B., Botbol, J. M., Billings, T. M., and Pierce, A. P., 1969, Geochemical abundance and distribution of nine metals in rocks and soils of the Coeur d'Alene district, Shoshone County, Idaho: U.S. Geol. Survey open-file rept., 3 p.

[20] Gott, G. B., Botbol, J. M., and Billings, T. M., 1970, Geochemical maps and statistical data, Coeur d'Alene district, Shoshone County, Idaho: U.S. Geol. Survey open-file rept., 11 plates, tables.

[21] Neuerburg, G. J., Botinelly, Theodore, and Kulp, K. E., 1970, The prospecting significance of hypogene iron oxide distributions in the Montezuma district, central Colorado: Am. Inst. Mining, Metall., Petroleum Eng., 11 p. [Preprint]

through which pneumatolytic ore fluids passed and thus indicate optimal areas for prospecting. The presence of unusual amounts of various metals such as bismuth, mercury, tin, and tungsten serves to identify magnetite and specularite that were involved in the pneumatolytic ore process.

Puerto Rico.—Geochemical soil surveys by R. E. Learned near several defined porphyry copper deposits in Puerto Rico indicated that gold is the most useful element for detecting these deposits in the overlying soils. Background gold values in soils were less than 0.2 ppm, whereas gold values in soils overlying the deposits ranged from about 0.1 to 1.5 ppm. Copper, lead, zinc, and silver values in soils did not consistently reflect the presence of the underlying deposits.

Mercury geochemistry

A. P. Pierce (r0671), J. M. Botbol, and R. E. Learned tabulated statistics on the mercury content of more than 25,000 samples of rock, soil, and sediments collected by Geological Survey geologists from widely separated areas in the central and western United States, Alaska, and Puerto Rico. The results indicated that levels of natural mercury concentration or abundance are extremely variable, with modal values ranging from about 10 to 6,000 ppb for sample sets from 13 areas in Western United States. Mercury concentrations of greater than 1,000 ppb in rocks and sediments and greater than 500 ppb in soils are unusual and are considered to be the result of the introduction of mercury by natural mineralizing processes or by surface contamination.

Using newly developed equipment, J. H. McCarthy, Jr. (r2181), J. L. Meuschke, W. H. Ficklin, and R. E. Learned conducted airborne mercury surveys over several porphyry copper deposits in Arizona and also over mercury deposits at New Idria, Calif., and Battle Mountain, Nev. All three areas revealed anomalous but low concentrations of mercury in air during the summer. The data suggested that lower concentrations of mercury in air are found in the summer months than at other times of the year; in addition, the magnitude and extent of mercury anomalies are influenced by both long- and short-term weather conditions.

In another study, J. H. McCarthy, Jr., W. W. Vaughn, and C. G. Bowles detected mercury vapor (as much as 60 ng/m^3) released by the oxidation of copper sulfide minerals at the Orphan and Riverview mines in Coconino County, northern Arizona. The association of mercury vapor with the copper-uranium ores of these mines suggests that the vapor may escape through the solution collapse structures that contain such ore bodies and eventually reach the surface. Mercury appears to be a useful pathfinder to use in prospecting for concealed uranium-copper deposits located in the breccia pipes of the Grand Canyon region of Arizona.

Soil gas sampler for mercury surveys

W. W. Vaughn has developed a hand-carried soil-gas sampler for mercury surveys. The sampler weighs about 7 lb and consists of an 11-inch-diameter staff-mounted, clear plastic hemisphere with provisions for continuously measuring air and soil temperature of the sample area as well as extracting mercury by amalgamation from a known volume of soil gas. Fair weather and decreasing barometric pressure favor the sampling process. The mercury extracted from the soil gas by the sampler is measured in a field laboratory using a modified Geological Survey mercury-vapor detector.

New exploration techniques

F. E. Senftle, R. M. Moxham, and A. B. Tanner have made studies of the feasibility of in situ neutron activation with a californium-252 neutron source as a useful technique in mineral exploration. They found that the detection of delayed gamma rays following neutron activation is not very sensitive for the transition group of elements. The measurement of prompt-capture gamma rays, however, was found to be a more sensitive technique for detecting ores of nickel, copper, and titanium.

G. J. Neuerburg, Theodore Botinelly, and J. R. Watterson determined that tellurides have a measurable vapor pressure. Because of this discovery, they suggested that tellurium might be present in soil gases over mineral deposits and that the measurement of this element in this form would represent a potentially useful new exploration technique.

W. C. Overstreet, J. L. Harris, and E. F. Overstreet[22] studied the major- and minor-element content of detrital pyralspite garnets from the inner Piedmont belt of North and South Carolina as a potential geochemical sampling medium for exploration in deeply weathered areas. They found that variations in the content of various elements in garnets can be correlated with the grade of progressive regional metamorphism and, to a lesser degree, with the original composition of the source rocks. The garnets are particularly sensitive indicators to changes in abundances of the rare earths, but they are rather insensitive indicators, compared to detrital magnetite in the same area, of changes in regional abundances of the ferroalloy elements and base metals.

Biogeochemical investigations

The use of plants in mineral exploration is continuing to command the attention of Geological Survey geochemists. H. L. Cannon and T. F. Harms found that the lithium content of halophytic vegetation from the Great Basin area of the Western United States is much higher than but closely related to the lithium content of the adjacent soil. Also, they found that lithium is concentrated to a much greater degree in plants which also accumulate sodium chloride. Lithium contents of

[22] Overstreet, W. C., Harris, J. L., and Overstreet, E. F., 1970, Minor elements in detrital garnets, North Carolina and South Carolina, U.S.A.: Geochemical prospecting techniques in the humid tropic environment, Joint UNESCO/ECAFE Seminar, Ceylon, Sept. 1970, Paper GSM(2)/24, 20 p. [Preprint]

as much as 3,000 ppm were found in the ash of pickleweed *(Allenrolfia)* and also in rushes rooted in soil near hot springs. An average of 150 ppm in the ash and 25.8 ppm in the dry weight of all plants that were collected in both hydraulically open and hydraulically closed basins is considerably higher than the average of 1.3 ppm in dry weight previously established for plants growing in more humid areas.

Statistics applied to geochemical prospecting

Statistical study and computer applications are becoming increasingly important in mineral exploration. J. M. Botbol developed a computer routine which interpolates geochemical data into unsampled areas thus allowing the application of smoothing and automatic contouring in the production of computer-created geochemical contour maps. The principle of the interpolations is analogous to the techniques used in producing equal-area contour plots in petrofabric studies.

Helmuth Wedow, Jr. (r1280), and G. E. Ericksen made an evaluation of log-probability plots of data obtained during reconnaissance geochemical exploration. They found that such plots are a reliable, rapid method for distinguishing the few potentially anomalous metal values from the large background population. Log-probability plots of data show complex curves that suggest mixtures of separate background and anomalous populations in proportions dependent upon the density of sampling in or near mineral deposits. The most conspicuous feature in such curves is the generally sharp break in slope at a threshold where the background population can no longer mask the high values of the more variable anomalous population. Truly anomalous values tend to cluster in mineralized terrane; on the other hand, scattered isolated values barely above threshold generally are not related to mineralization but represent the few random high values that can be expected in a large suite of normal background data.

New analytical methods

Three new analytical methods have been added to the rapidly expanding list of methods for use in geochemical exploration.

G. A. Nowlan[23] developed a new rapid colorimetric field method for the determination of cold-extractable nickel in stream sediments and soils. The method uses a dilute, cold nitric acid leach followed by buffering and extraction of the nickel into a solution of α-furildioxime dissolved in benzene. A concentration range of 0.25 to 60 ppm can be detected with a 0.2-g sample.

M. A. Chaffee (r0615) developed a simple, rapid, and sensitive atomic absorption method for the determination of both acid-soluble and total manganese in geological and botanical materials. Samples are digested with hydrochloric or nitric acid in the acid-soluble procedure or with hydrofluoric, perchloric, and nitric acids in the total procedure. With a 0.1-g sample, concentrations as low as 20 ppm can be determined in a variety of natural materials.

A spectrographic method for the semiquantitative determination of trace elements in native gold was developed by E. L. Mosier. Because gold is analyzed in its native state, this method avoids the necessity of complicated sample preparation. A set of standards is prepared in a graphite matrix and arced in the presence of pure gold and lithium carbonate to create an environment within the arc of the standards that approximates the environment of the sample arc, thus eliminating variations caused by matrix effects. The method provides analytical data on a wide range of elements at low levels of detection, including highly volatile elements closely associated with gold, such as arsenic, mercury, tellurium, and zinc.

Exploration geophysics research

The results of airborne VLF surveys showed, according to F. C. Frischknecht, that measurement of the horizontal electric field is very useful in qualitatively mapping the resistivity of near-surface rocks. In topographically flat areas both in-phase and quadrature components of the horizontal electric field can be measured. In areas of fairly rugged topography, however, the in-phase component is useless; the quadrature component, on the other hand, is much more dependent on the resistivity of the rocks than on topography and can still be utilized. Scale model measurements indicate that many times the horizontal electric field should be of more use in mineral exploration than the magnetic field components.

RESOURCE COMPILATIONS

Energy resources

In a recently published summary, Paul Averitt (r0704) concluded that the potentially recoverable resources of stripping coal in the United States to a maximum depth of 150 feet below the surface totaled 128 billion tons as of January 1, 1970. This huge amount is 29 times the cumulative of all coal recovered by strip mining methods to January 1, 1970, and it is 690 times the amount of coal strip mined in 1969.

The strippable coal deposits are widely distributed in 26 States, but significantly large amounts are present in the northern Great Plains region of western North Dakota, eastern Montana, and northeastern Wyoming; the Illinois basin; and the north half of the Appalachian basin.

Geologic distribution of resources

P. W. Guild (r1564) in a recent publication points out that distribution of the mineral deposits of the world can be fitted into concepts developed by new concepts of global tectonics.

[23] Nowlan, G. A., 1970, A field method for the determination of cold-extractable nickel in stream sediments and soils, *in* Geological Survey Research 1970: U.S. Geol. Survey Prof. Paper 700-B, p. B177–B180.

For example, many of the orogen-associated deposits of Mesozoic and Tertiary ages occur near the postulated sites of collisions between continental and oceanic plates; most of the others coincide geographically with island arc–oceanic plate collisions. Grouping deposits by their loci of formation with respect to the plates (within, or at margins of different types) leads to a classification that permits them to be related to major earth events. Improved understanding of the reasons for concentration of elements into ore bodies will aid exploration planning and also, with petrologic, metamorphic, and structural data, provide criteria for deciphering the older history of the earth (for example, locating former subduction zones and delineating ancient plates).

Resource files

J. A. Calkins has undertaken the task of updating and putting into a format acceptable for computer-based storage and retrieval, a large part of the commodity resource data and information now held in conventional files of the Geological Survey. The new file will permit quicker and more accurate searches of material on hand in response to requests for resource information.

MINERAL INVESTIGATIONS RELATED TO THE WILDERNESS ACT

The Wilderness Act of 1964 directs the Secretary of Agriculture and the Secretary of the Interior to review the suitability or nonsuitability of lands being considered for inclusion in the National Wilderness Preservation System. As one aspect of the reviews, the U.S. Geological Survey and the U.S. Bureau of Mines are making mineral surveys of primitive and other areas of the national forests that are being considered for wilderness inclusion. Mineral surveys also are under way of wilderness areas that were established by the Wilderness Act.

PRIMITIVE AREAS

Mineral surveys have been completed and the reports published as Geological Survey bulletins on 22 of the 34 primitive areas that are identified with the Wilderness Act. Reports on two primitive areas (Wilson Mountains, Colo., and Popo Agie, Wyo.) were in press as of June 1971, as is a report on the Pasayten Wilderness which formerly was part of the North Cascades Primitive Area, Wash. Fieldwork on two primitive areas (Beartooth, Mont., and Absaroka, Mont.) will be continued in 1972, but fieldwork on all other primitive areas is completed.

In 1971, reports were published for the primitive areas described below.

Sawtooth, Idaho

The Sawtooth Range is made up chiefly of granitic rocks of the Idaho batholith, which, in the northern part, are intrusive into metamorphic rocks of probable Precambrian age.[24] Intrusive into the Idaho batholith is a pink granite, the Sawtooth batholith that is believed to be middle Tertiary in age. Cutting all the rocks are swarms of Tertiary dikes and many faults of which two, the Montezuma fault on the southwest and a more or less parallel major fault on the northeast, mark the limits of a horst from which the range has been carved.

The mineral survey of the Sawtooth Primitive Area, central Idaho, by T. H. Kiilsgaard (r0086), V. L. Freeman, and J. S. Coffman covered an area of 434 sq mi. The report directs attention to the structural control of the Montezuma fault on mineral deposition. Along the western or downthrown side of the fault, for a distance of more than 16 mi, are many veins that have been mined primarily for gold and silver. Included in this belt of deposits are those of the Atlanta mining district. Prospecting along the belt dates from the 1860's, and the mineralized character of the belt is likely to encourage exploration in the future.

A number of mineralized localities were found in the primitive area, including some enriched in molybdenum along Tertiary dikes. One property near the mouth of Rock Creek has been prospected to some extent for molybdenite and galena.

An unexpected discovery was the enriched metal content of the Sawtooth batholith. Samples of the batholith rocks and of sediments from streams that drain areas underlain by the batholith are decidedly more enriched in molybdenum, beryllium, niobium, and uranium than are samples from the surrounding Idaho batholith. The uranium content of the Sawtooth granite makes it comparable to the Conway Granite of New Hampshire.[25]

Gore Range—Eagles Nest, Colo.

Ogden Tweto (r0708) and Bruce Bryant describe the Gore Range as a fault block of Precambrian rocks between the Gore fault on the west and the Frontal fault on the east. At the south, the range extends into the border zone of the Colorado mineral belt, which in this region includes the highly productive mining districts of Climax, Leadville, Gilman, and other lesser ones. The Mosquito fault, one of the controlling features of the ore deposits at Climax and Leadville, extends into the southern part of the Gore Range and connects with both the Gore and Frontal faults. All three of these faults and many

[24] Reid, R. R., 1963, Reconnaissance geology of the Sawtooth Range: Idaho Bur. Mines and Geology Pamph. 129, 37 p.

[25] Brown, K. B., Hurst, F. J., Crouse, D. J., and Arnold, W. D., 1963, Review of thorium reserves in granitic rock and processing of thorium ores: Oak Ridge Natl. Lab., ORNL-3495, 25 p. (report prepared for U.S. Atomic Energy Comm.).

others in the range are old faults that were reactivated when the range was elevated to its present height in late Tertiary time.

No mineral production is recorded from the Gore Range Primitive Area nor is the area known to contain any economically significant mineral deposits. Veins and veinlets of quartz or carbonate minerals along some of the fault zones contain ore minerals in small and subcommercial amounts. Many of the fracture zones are anomalous in Cu, Pb, Zn, Ag, Au, Mo, Bi, As, Sb, and Hg, but the area is devoid of porphyry intrusive bodies such as characterize the adjoining Colorado mineral belt, and, except in narrow zones along some faults, it contains no hydrothermally altered areas. The anomalous metals were deposited in the fracture system after the latest major uplift of the range in late Tertiary time; therefore, they are not related to the mineralizing episodes that created ore deposits in the nearby Climax, Leadville, and Gilman districts but are younger.

Agua Tibia, Calif.

The Agua Tibia Primitive Area includes about 43 sq mi of the Cleveland National Forest in southwestern California. W. P. Irwin (r0085), R. C. Greene, and H. K. Thurber note that the area is underlain chiefly by granitic rocks of the Peninsular Range batholith and by remnants of intruded sedimentary and volcanic rocks that have been metamorphosed. The Elsinore fault, a major fracture zone, trends northwesterly along or near the southwest boundary of the area.

No mineral concentrations of economic value or evidence of former mining activity were found within the primitive area. Analyses of stream sediment and bedrock samples failed to reveal any evidence of minable deposits in the area. A positive magnetic anomaly disclosed by an aerial survey is related to a body of gabbro and not to a magnetic mineral deposit of commercial significance. Mineral production from gem-bearing pegmatites of the nearby Pala and Rincon districts is relatively small. The gem-bearing pegmatites are separated from the primitive area by the Elsinore fault, and the absence of similar pegmatites in the primitive area may be attributable to large-scale displacement along the fault.

Black Range, N. Mex.

A mineral survey of about 565 sq mi of the Black Range Primitive Area and contiguous tracts has been made by G. E. Ericksen (r0707), Helmuth Wedow, Jr., and G. R. Leland. These investigators found the primitive area to be underlain largely by a thick sequence of volcanic rocks that are units of the Datil Formation of Tertiary age. These rocks rest unconformably on older volcanic rocks of early Tertiary age, which in turn overlie Paleozoic sedimentary rocks. Dikes and small bodies of quartz monzonites intrude the early Tertiary and older rocks, and rhyolite dikes intrude many units of the Datil Formation. Many north-trending steeply dipping faults cut the rocks of the area.

Mineral deposits have been mined from the early Tertiary and older rocks in the Chloride, Hermosa, Kingston, and Carpenter mining districts, at distances of 1 to 10 mi outside the primitive area, but no mineral production is recorded from within the area nor were indications of commercial or potentially commercial deposits found. Nonminable occurrences of kaolin, perlite, moonstone, topaz, and tin were found, but the investigators conclude that geologic processes that result in the formation of ore deposits were not active in the primitive area in Datil or post-Datil times; consequently, it is unlikely that minable deposits occur in the Datil rocks that blanket most of the area. By contrast, minable deposits of Ag, Pb, Zn, and Cu may exist in the early Tertiary and older rocks that are buried beneath the Datil Formation.

Emigrant Basin, Calif.

The Emigrant Basin Primitive Area is immediately west of the crest of the central Sierra Nevada, California. According to E. W. Tooker, H. T. Morris, and P. V. Fillo,[26] it consists of about 180 sq mi of scenic mountains composed chiefly of granitic rocks of the Sierra Nevada batholith and of remnants of moderately to strongly metamorphosed sedimentary rocks, all of which are cut by many dikes and covered by scattered patches of a once extensive blanket of late Cenozoic latite and andesite lavas, tuffs, and breccias.

No mineral deposits of commercial value were found in the greater part of the proposed wilderness; however, in the southeastern part of the area are some metamorphosed roof-pendant rocks in which are small, scattered bodies of scheelite. Small quantities of scheelite have been mined at two properties, the Montezuma mine near Snow Lake and the Cherry Creek mine near Sachse Monument. Other tungsten occurrences in the metamorphosed limestone and limy shale pendant have been prospected and may be expected to generate further prospecting interest, particularly in times of high tungsten prices or national emergencies.

Glacier, Wyo.

A mineral survey of the Glacier Primitive Area, Wyo., by the U.S. Geological Survey and the U.S. Bureau of Mines, is described by H. C. Granger (r1887), E. J. McKay, R. E. Mattick, L. L. Patton, and Paul McIlroy. The area that was studied, about 342 sq mi along the northeast flank of the Wind River Range in western Wyoming, is underlain chiefly by granites and gneissic rocks of Precambrian age. The rocks are cut by Precambrian diabase dikes, and, along the northeast edge of the area, are flanked by a sequence of Paleozoic

[26] Tooker, E. W., Morris, H. T., and Fillo, P. V., 1970, Mineral resources of the Emigrant Basin Primitive Area, Calif.: U.S. Geol. Survey Bull. 1261-G, 70 p.

sedimentary rocks. A complex network of faults cuts the rocks.

No mineral deposits that can be mined economically were disclosed by the study. A small amount of uranium ore has been mined from a breccia zone in biotite gneiss in Little Warm Spring Creek valley, a few miles north of the primitive area, but the deposit is considered to be of supergene origin and not extensive. Traces of uranium also have been found in the vicinity of Whisky Mountain, west of the area, but the deposits are low in uranium content and not of economic grade. Iron-bearing shales of the Amsden Formation crop out in the upper reaches of Red Creek and Little Red Creek. The red shale unit is about 50 feet thick at one locality, with the lower 12 feet richer in iron than the remainder. Much of the iron is concentrated in lenses that are typically a few inches thick, several tens of feet across, and consist chiefly of concentrically banded oolites composed of goethite, hematite, and kaolinite interspersed with and partly included in irregular masses of hematite. A sample taken from a bed 6 feet thick contained 19.6 percent iron.

PROPOSED WILDERNESS AREAS

Lincoln Back Country, Mont.

Parts of national forests not presently classified as primitive areas are being proposed for inclusion in the National Wilderness Preservation System. Typical of these is the Lincoln Back Country Area, a tract of 375 sq mi in the Helena, Lolo, and Lewis and Clark National Forests, Lewis and Clark and Powell Counties, Mont. The mineral potential of this area was investigated by M. R. Mudge (r1003), R. L. Earhart, K. C. Watts, Jr., E. T. Tuchek, and W. L. Rice, and the report made available to public review.

Precambrian sedimentary rocks (Belt Supergroup) are the principal rocks of the area. They have been intruded by diorite sills of Precambrian age and by sills of uncertain age that are of monzonite to andesite composition. The rocks have been folded and broken by thrust and normal faults.

Copper was the only mineral found of possible economic value, and it occurs in two unrelated types of deposits: (1) quartz-carbonate veins in the southern part of the area, and (2) associated with green beds in Precambrian sedimentary rocks.

The near-vertical veins, ¼ inch to 2 feet wide, crop out discontinuously in a belt about 10 mi long. At a prospected locality on Bugle Mountain, the veins form a pattern 110 feet wide. Small sporadic ore shoots are found in the veins in which the copper minerals include, in order of abundance, bornite—which locally makes up 40 percent of the sulfide minerals of the vein—malachite, chalcopyrite, and chalcocite. Galena and sphalerite and minor amounts of molybdenite and tetrahedrite also are found in the veins. The belt has been prospected at a number of sites, but the known material is too low in volume and grade to be minable at present.

Malachite, bornite, azurite, chalcopyrite, and chalcocite, in green to greenish-gray argillites, siltites, and quartzites, are widespread throughout the Lincoln Back Country Area, but the occurrences are small and the copper content is low. The mineralized occurrences are mostly in the Spokane, Empire, and Snowslip Formations but also occur in the Helena Dolomite, Shepard, Mount Shields, and McNamara Formations. The minerals are along fractures, along bedding planes, and in the intergranular voids of porous rocks where the abundance of minerals increases proportionately to the grain size of the rock. Copper-bearing strata commonly range in thickness from less than 1 inch to about 1 foot; rarely they reach as much as 3 feet in thickness. Lateral continuity ranges from a few inches to about 200 feet.

WILDERNESS AREAS

Field investigations are under way in the following wilderness areas: Chiricahua, Ariz.; Mt. Zirkel, Colo.; Bob Marshall, Mont. (recessed in 1971); Gila, N. Mex.; San Pedro Parks, N. Mex.; Eagle Cap, Oreg.; and North Absaroka, Wyo.

OFFICE OF MINERALS EXPLORATION

The U.S. Geological Survey, through its Office of Minerals Exploration (OME) under Public Law 85-701, offers a program of financial assistance on a participating basis to private industry to seek deposits of certain eligible minerals. Assistance 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. Prospecting ventures or projects to develop properties for mining are not eligible for assistance.

An applicant must have rights of possession to a specific property he wishes to explore for a period of time at least sufficient to complete the exploration. A reasonable geologic probability must exist of a significant discovery of ore being made on the property by the exploration specified in a contract. Repayment of Federal funds expended on a contract plus simple interest is made through a 5-percent royalty on mineral production from the property. If the Government issues a certification of possible production, the royalty period continues for a stated period of time, usually 10 years, or until the principal and interest are repaid in full, whichever occurs first. In the event that there is no production, no repayment is required. The Government is not obligated to purchase any production.

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

Asbestos	Manganese
Bauxite	Mica (strategic)
Beryllium	Molybdenum
Cadmium	Monazite
Chromite	Nickel
Cobalt	Quartz crystal (piezo-electric)
Columbium	Rare earths
Copper	Selenium
Corundum	Sulfur
Diamond (industrial)	Talc (block steatite)
Fluorspar	Tellurium
Graphite (crucible flake)	Thorium
Iron ore	Uranium
Kyanite (strategic)	

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

Antimony	Rutile
Bismuth	Silver
Gold	Tantalum
Mercury	Tin
Platinum-group metals	

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

Contracts to explore for silver have accounted for more than 40 percent of the total value of all contracts as the following table shows:

Principal commodity	Number of contracts	Total value of contracts	Percentage of total value
Silver	67	$5,131,319	43.0
Gold	53	2,671,284	22.4
Mercury	16	1,118,780	9.4
Copper	13	743,410	6.2
Lead-zinc	7	682,030	5.7
Lead-zinc-copper	11	487,641	4.1
Molybdenum	3	384,438	3.2
Iron	3	199,580	1.7
Beryllium	3	127,440	1.1
All others (cobalt, fluorspar, mica, nickel, platinum, uranium).	10	382,970	3.2
Total (15 commodities)	186	$11,928,829	100.0

Actions on the OME program in calendar year 1970 and totals for the program through December 31, 1970, were as follows:

	Calendar year 1970	Program totals 1959 through 1970
Applications		
Received	30	[1]866
Denied	22	359
Withdrawn	16	298
Processing completed	25	825
Total in process Dec. 31, 1970	23	....
Contracts		
Executed	5	186
Total value	$215,305	$11,928,892
Government share	$132,205	$ 6,824,072
Government share spent	[2]$314,500	$ 4,145,764
Repaid to Government through royalties on production.	$129,413	$ 386,183
Estimated recoverable value of reserves in year discovered.	$2.8 million	$81.8 million

[1]Total estimated cost of proposed exploration, $84,488,054.
[2]Disbursements on all active contracts during the year.

GEOLOGICAL, GEOPHYSICAL, AND MINERAL-RESOURCE STUDIES

NEW ENGLAND

STRUCTURAL AND STRATIGRAPHIC STUDIES

Oroflexes in northern Maine

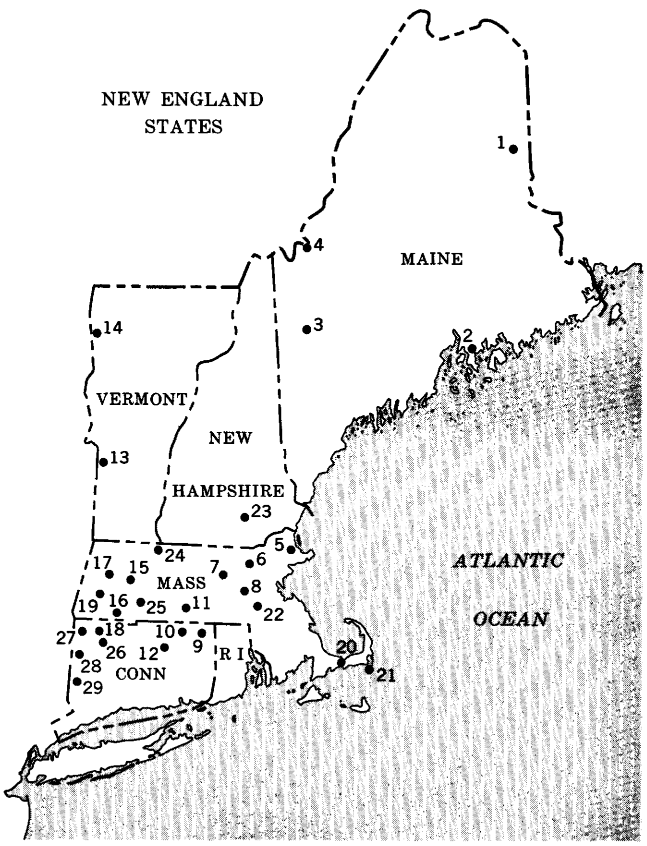
Louis Pavlides reports that a pronounced oroflex or sigmoidal warp[27] in the regional trend of folded rocks occurs near the south end of the Aroostook-Matapedia anticlinorium, northern Maine.[28] The major change in trend of the oroflex occurs near Houlton (locality 1, index map). Immediately to the north the anticlinorium generally trends northerly, but west of Houlton the trend is westerly and eventually becomes southwesterly. The change in trend involves both the secondary fold axes of the anticlinorium and the slaty cleavage which generally parallels the fold axes. This Houlton oroflex is a late Acadian feature, as it warps Acadian-age folds and associated cleavage and is itself intruded by post-Acadian (385–400 m.y.) felsic plutons. The emplacement of these plutons may have been structurally controlled, in part, by the warping that produced the oroflex, as the plutons are situated near the cross axis of the oroflex.

Approximately 12 mi west and northwest of the Houlton oroflex is the Howe Brook oroflex, as outlined by the core

[27] Albers, J. P., 1967, Belt of sigmoidal bending and right-lateral faulting in the Western Great Basin: Geol. Soc. America Bull., v. 78, p. 143–156.

[28] Pavlides, Louis, 1968, Stratigraphic and facies relationships of the Carys Mills Formation of Ordovician and Silurian age, northeast Maine: U.S. Geol. Survey Bull. 1264, 44 p.

rocks of the Weeksboro–Lunksoos Lake anticline.[29] The trends of the axes of the Houlton and Howe Brook oroflexes are virtually parallel, and the hinge areas of the respective oroflexes define a northwest-trending "cross fold" passing near the town of Houlton and the railroad siding of Howe Brook. This "cross fold" axis when extended northwestward appears to intersect another possible oroflex, as defined by the northwest-trending anticline of Orcutt Mountain and the northeast-trending Munsungun anticlinorium.[30]



The origin of the Houlton and Howe Brook oroflexes is uncertain; they may have originated in response to compression from southwestward directed forces or even as quasi-dextral flexures in response to a shear couple involving movement of crustal blocks to the northwest and southeast of them.

Calc-silicate rocks in northeast Maine

In the Smyrna Mills quadrangle (loc. 1) of northeastern Maine,[28] distinctive calc-silicate mineral assemblages have developed in the impure thin-bedded limestones of the Carys Mills Formation where these strata strike into the thermal aureole of Devonian felsic plutons. Louis Pavlides reports that the contact-metamorphosed limestones are fine grained, with well-preserved original layering. Near the margins of the aureole, weakly metamorphosed limestone is distinguished from nonmetamorphosed limestone by its more brittle character and the appearance of pale-purplish colors in pelitic interbeds. Increasing metamorphism in the inner parts of the aureole results in well-layered rocks of gray (carbonate and some tremolite), dark-purple (biotitic), and greenish (diopsidic) colors. In general, tremolite occurs chiefly in the outer parts of the contact aureole, whereas diopside is more common in the inner parts.

Locally, very high rank calc-silicate assemblages (pyroxene-hornfels facies) are present close to epizonal, high-temperature perthitic granite plutons and as selvages along granitic dikes. These calc-silicates have compositional layering (original bedding) that typically consists of greenish-white and gray beds with dark-purplish-gray interbeds and irregular, coarse-grained, idocrase-rich layers interspersed between bright-green diopsidic layers. Individual layers commonly contain wollastonite-diopside-calcite-grossularite and idocrase-wollastonite-diopside assemblages, whereas the purplish layers are biotitic and may contain diopside, cordierite(?), and calcic plagioclase. Calcite-diopside-scapolite and diopside-quartz-cordierite assemblages are rarer. These pyroxene facies calc-silicate rocks comprise the highest rank metamorphosed rocks known in northern Maine.

Ordovician and Precambrian rocks in southeastern Maine

D. B. Stewart, in collaboration with D. G. Brookins (Kansas State University), reports that Rb-Sr dating has confirmed the Ordovician age of the Penobscot Formation in the Blue Hill–Castine area, Maine (loc. 2). These rocks of the Penobscot are similar to rocks near Rockland, Maine, where orthoid brachiopods of European affinities were discovered by C. V. Guidotti (University of Wisconsin), and probably with the Navy Island Formation at St. John, New Brunswick. Also reported is a Precambrian Rb-Sr age of 900±100 m.y. for high-grade metamorphic rocks at Isleboro, Maine; these rocks are cut by pegmatites dated at 600±25 m.y. These are the first unequivocally Precambrian rocks to be reported from Maine.

Structure in western Maine

A major problem with the concept of premetamorphic large-scale down-to-basin slump faulting in western Maine (R.H. Moench, r2516) has been the lack of evidence that the principal slump faults of that area actually flatten with depth, toward the axis of the Merrimack sedimentary trough. Evidence for such flattening was found during recent mapping by R. H. Moench and C. T. Hildreth in the southwest part of the Rumford quadrangle (loc. 3). There, previously defined detailed stratigraphic units (R. H. Moench, r2516) are map-

[29] Pavlides, Louis, Mencher, Ely, Naylor, R. S., and Boucot, A. J., 1964, Outline of the stratigraphic and tectonic features of northeastern Maine, *in* Geological Survey Research 1964: U.S. Geol. Survey Prof. Paper 501-C, p. C28–C38.

[30] Hall, B. A., 1964, Stratigraphy and structure of the Spider Lake quadrangle, Maine: Yale Univ., Ph. D. dissert., 153 p.

pable and were found to be truncated along a newly discovered premetamorphic fault. This fault, the Plumbago Mountain fault, is similar to other premetamorphic faults in the area, but it has been folded by large, superposed late folds that plunge gently to the southwest, so that it is now exposed along three lines instead of one in this structurally complex area. This fault separates two folded plates. The upper plate contains younger rocks which are exposed in the south and in the late syncline between the two northern fault lines. On the basis of the regional geology, the present northernmost faultline is taken as the approximate original faultline of the Plumbago Mountain fault prior to late folding. A south-facing sequence of younger rocks (mostly Devonian) on the south side of this faultline is downthrown against a north-facing sequence of older rocks (mostly Lower Silurian) on the north. Thus, the Plumbago Mountain fault is interpreted to be a normal fault that dipped south and flattened with depth toward the south in order to have been folded to its present configuration.

In the Chain Lakes quadrangle (loc. 4) E. L. Boudette (r2263) reports that Precambrian(?) rocks of the Chain Lakes massif are arranged in either a broad, northeasterly plunging arch or possibly an elongate dome doubly plunging in the northeast-southwest tectonic grain of the region. If the latter is true the gross structure of the massif rocks is approximately conformable to the geometry of the Boundary Mountains anticlinorium. The rocks of the massif are divided into a lower unit comprised of massive to faintly bedded granofels and gneiss, and an upper unit comprised of well-bedded gneiss, schist, metavolcanic rocks, metasandstone, and thin-layered amphibolite. The lower unit has an unusual fragmental texture of undetermined origin. Rocks of the massif show a pervasive bedding foliation, but fragments in the lower unit commonly show a primary schistosity at variance with the bedding foliation. In massif rocks on the northwest limb of the arch, quartz monzonite of the Seven Ponds pluton of Devonian age occurs as sheets conformable to the bedding. Thus, the pluton appears to be grossly tabular in its center, dipping regionally to the northwest. Possibly the sheets of the pluton continued over the crest of the arch to the southeast limb in a higher level of the crust than presently observed.

Cape Ann batholith in northeastern Massachusetts

Detailed mapping of the Cape Ann batholith (loc. 5) in the Ipswich and Marblehead North quadrangles by W. H. Dennen and in the Georgetown, Salem, Reading, Lynn, and Boston North quadrangles by K. G. Bell indicates that this pluton consists of a comagmatic series ranging from gabbro to granite and syenite. Greenish microperthite and plagioclase are characteristic constituents of this magma series. The Cape Ann Granite in the Ipswich and Marblehead North quadrangles shows an alinement of quartz and xenolith trains parallel to the regional grain of the metamorphic rocks. These features possibly reflect the slope and stratigraphy of the roof of the batholith. Dikes within the Cape Ann Granite are offset in many places without noticeable disruption of the granite, indicating movements within the granite after emplacement of the dikes. The diorites and gabbros previously have been included in the Salem Gabbro-Diorite of Clapp[31] and Emerson[32]. Separation of the mafic Cape Ann rocks from other mafic rocks of the region will necessitate a redefinition of existing geologic names or substitution of new names. Petrographic and chemical studies of these rocks have not been completed.

Structure and stratigraphy of northeastern Massachusetts

A. F. Shride and K. G. Bell have shown that andesitic flows and pyroclastics dominate the Newbury Formation (Silurian or Devonian) in the Newburyport West, Newburyport East, Georgetown, and Salem quadrangles (loc. 5). Laminated rhyolitic tuffs form a lesser but conspicuous part of the volcanic complex. Additionally, these studies have revealed a possible pre-Newbury Formation unconformity. Three excavations have uncovered a saprolitic and lateritic zone on intrusive and minor amounts of stratified rocks, all thought to be of pre-Silurian age. It also is possible that this weathered zone represents a pre-Pleistocene surface. No natural exposures of this surface have been seen; any additional exposures undoubtedly will be uncovered during construction projects.

In the Lowell, Westford, Billerica, and Concord quadrangles (loc. 6) complexly interstratified metamorphosed volcaniclastic and epiclastic rocks of the Nashoba Formation[33] crop out in a northeast-trending belt that varies in width from 52,000 to 62,000 feet. Mapping by D. C. Alvord has shown that most of the rocks within this belt are medium- to coarse-grained quartz-sodic plagioclase-biotite gneiss with variable amounts of muscovite, sillimanite, and garnet. Irregularly, throughout the sequence, there are lesser amounts of fine- to medium-grained amphibole-plagioclase-biotite gneiss and schist, quartz-feldspar-diopside calc-silicate granofels, and fairly aluminous quartz-plagioclase-muscovite-biotite-sillimanite schist. These rocks retain many primary features characteristic of subaqueous sediments, although they are sillimanite-muscovite grade. Bedding and foliation generally strike N. 50°–60° E. and dip within 20° of vertical. This homoclinal sequence has been mapped southeastward without important interruption to a contact with igneous rocks, along which there is evidence of faulting. Locally Nashoba rocks have been identified southeast of these igneous rocks and there interpreted to have a gradational contact with the underlying(?) Marlboro Formation. The northwest margin of the Nashoba is marked by an unnamed but regionally persistent unit of rusty-weathering

[31] Clapp, C. H., 1921, Geology of the igneous rocks of Essex County, Massachusetts: U.S. Geol. Survey Bull. 704, 132 p.

[32] Emerson, B. K., 1917, Geology of Massachusetts and Rhode Island: U.S. Geol. Survey Bull. 597, 289 p.

[33] Hansen, W. R., 1956, Geology and mineral resources of the Hudson and Maynard quadrangles, Massachusetts: U.S. Geol. Survey Bull. 1038, 104 p.

medium- to coarse-grained muscovite-quartz-andalusite-biotite-sillimanite schist which in this area forms an outcrop belt 3,000 to 5,000 feet wide. The unit is cut off on its northwest flank by the Clinton-Newbury fault. To date, field studies along 5 mi of contact in the Billerica area strongly indicate that pelitic strata of the unnamed schist are intertongued and gradational with the underlying(?) Nashoba Formation of quartz-sodic plagioclase-biotite gneiss, amphibolite, and lime-silicate granofels units. However, data from aeromagnetic maps that cover more than 36 mi of the subject contact strongly indicate that units of the Nashoba are truncated at low angle by the overlying pelitic schist, and a reasonable case for an important disconformity can be made. Rapid facies changes, intertonguing, small-scale folding, and several faults are found within the Nashoba, but mappable folds are lacking. Although the sequence is swollen or eliminated in places by sills or other masses of well-foliated felsic intrusive rocks, the Nashoba of the Billerica area is probably between 45,000 and 50,000 feet thick.

Metasedimentary rocks of probable Silurian to Devonian age have been mapped in the Clinton quadrangle (loc. 7) by J. H. Peck. The rocks make up more than 25,000 feet of metamorphosed marine-deposited mudstone, siltstone, fine-grained sandstone, and limy sandstone. Primary sedimentary structures within the rocks such as tabular bedding, thin laminations, cross-stratification, graded bedding, compositional banding, and rarely ripple marks and sole markings aid in the interpretation of the stratigraphic sequences and depositional environment of the original sediments. Most of the sediment was fine grained and laid down in a marine environment of mostly low energy, probably moderately deep to deep water, receiving periodic influx of clastic material. In general, the strata show a decrease in grain size upward and a change from feldspathic sands and silts at the base, through interlayered silts and clays, to thick carbonaceous and aluminous clays at the top. These changes probably reflect the progressive maturity of weathering of rocks in the source areas.

Faulting is the dominant structural feature in the Framingham quadrangle (loc. 8). The predominant faults trend easterly, are right lateral, and are accompanied by parallel zones of cataclastic rocks. North-trending subsidiary faults are also present. Work to date by A. E. Nelson shows that the principal easterly trending fault is a continuation of a fault that extends into the adjoining Natick and Newton quadrangles to the east, and into the Marlboro quadrangle to the west. This fault is a conspicuous structural feature in eastern Massachusetts and shows up as a distinct lineament on aeromagnetic maps.

Structure and stratigraphy of northern Connecticut and southern Massachusetts east of the Connecticut River

Recent work in northeastern Connecticut (loc. 9) has revealed a series of north-northeast-trending thrust faults along which the rocks have been moved from west to east. H. R. Dixon recognizes four of these faults in the Thompson and Putnam areas, Connecticut. The lowermost and probably the major fault is the Lake Char fault, which, along most of its trace, appears to be a discrete plane separating the metavolcanic rocks of the Quinebaug Formation in the upper plate from the granitic gneisses of the Sterling Plutonic Group and the quartzites and quartz schists of the Plainfield Formation in the lower plate. Locally, in the middle of the Thompson quadrangle, a zone of imbricate faults mixes rocks of the upper and lower plates. Several thousand feet west of the Lake Char fault is a complex imbricate fault zone along or just above the contact between the Tatnic Hill Formation and the underlying Quinebaug Formation. Along this fault zone high-grade metamorphic rocks (sillimanite-potassium feldspar) overlie lower grade rocks (sillimanite-muscovite). The next fault to the west is near or coincident with the trace of the axial surface of the recumbent Hampton syncline. Where best exposed, it separates the Hebron Formation from a sill-like body of heterogeneous granitic gneiss, called Ayer Granite by Emerson,[32] which is possibly equivalent to the Canterbury Gneiss. Still farther west the Eastford fault, first mapped by M. H. Pease, Jr., separates the Hebron Formation from the Paxton Quartz Schist.

The thrusts, at least within the Putnam quadrangle, are marked by zones of cataclastic and mylonitic rocks that are thickest adjacent to the two lower faults. The age of cataclasis and thrusting cannot yet be determined but must have been younger than regional metamorphism and major folding. Metamorphic zones are offset along the faults; the cataclastic rocks contain mineral assemblages typical of high-grade regional metamorphism, and early folds are truncated by small thrust faults subparallel to the larger ones. The relationship between these faults and faults currently being mapped in northeastern Massachusetts cannot be determined until more mapping in southern Massachusetts is completed.

M. H. Pease, Jr., has traced the Eastford fault southwestward from the Eastford quadrangle (loc. 10) through part of the Spring Hill quadrangle, Connecticut. New information derived from geologic, geophysical, and remote-sensing data not available to earlier workers in the area has shown that the Eastford fault represents the southeastern boundary of an imbricated fault wedge of Brimfield Schist and Paxton Formation apparently thrust over a broad recumbent syncline mapped throughout most of eastern Connecticut. The trace of the fault bends more westerly in the vicinity of Chaplin, Conn., but has yet to be mapped farther west. The wedge is bounded on the west by the north-south-trending Monson Border fault.

According to J. D. Peper the Monson Border fault can be traced from as far south as the middle of the Rockville quadrangle, Connecticut, to as far north as the northern border of the Palmer quadrangle, Massachusetts (loc. 10 and 11). This fault brings Monson Gneiss and other rocks of the Bronson Hill anticline southward and eastward over the

Brimfield rocks. West of the Monson Border fault, the rocks of the Bronson Hill anticline and superimposed Bolton syncline are much less faulted than the rocks in the wedge to the east.

In the eastern part of the wedge G. E. Moore, Jr., reports that the Brimfield Schist of the Southbridge quadrangle (loc. 11) contains distinct lime-silicate and metavolcanic units among the more abundant quartz-feldspar-mica-garnet-sillimanite schist and gneiss. The underlying Paxton Quartz Schist, to the east, is mostly quartz-feldspar-biotite gneiss and was not divided. Both formations contain many pods of foliated coarse- to medium-grained quartz-feldspar pegmatite. The contact between the two formations is a fault north of the city of Southbridge; to the south the contact may diverge from the fault and be a gradational sedimentary contact. Both the sillimanite rocks and the pegmatite are potentially of economic value.

Farther west J. D. Peper and M. H. Pease, Jr., have mapped a stratigraphic and structural sequence within the imbricated fault wedge in the vicinity of the Massachusetts-Connecticut State line (loc. 10). They have subdivided the Brimfield Schist of Emerson[32] into three formations, all of which are metamorphosed: Formation A consisting dominantly of calcareous sandstone and sandy shale, minor euxinic shale, and volcaniclastic rocks; Formation B consisting dominantly of schist derived from euxinic shale and volcaniclastic debris, and gneiss derived from euxinic and noneuxinic volcaniclastic debris, tuffs, lava, and hypabyssal sills of mafic to acid compositions; and Formation C consisting of noneuxinic sandstone, sandy shale, and shale, minor orthoquartzite, and rare euxinic shale. In the eastern and central parts of the wedge, Formation B overlies Formation A along a thrust fault that has been traced southward to the Monson Border fault in the Rockville quadrangle. Both formations lie in a west-facing homoclinal sequence that is corrugated by small-scale north-plunging asymmetric and overturned folds. In the western part of the belt, Formation C unconformably(?) overlies Formation B in an isoclinally folded and thrust-imbricated fault block paralleling the Monson border. Formation C is equivalent to the Littleton Formation, and Formation B is equivalent to the Partridge Formation mapped by others to the north in north-central Massachusetts along the eastern edge of the Bronson Hill anticlinorium. The age of rocks in Formations B and A in the homoclinal sequence in the central and eastern parts of the wedge may be as old as Middle Ordovician or as young as Early Devonian.

Preliminary field mapping by J. S. Pomeroy in the Warren quadrangle (loc. 11), Massachusetts, reveals gray-weathering quartz-feldspar-biotite-garnet-sillimanite schist and gneiss overlying a rusty-weathering sequence of similar mineral composition. These units were noted by J. D. Peper and M. H. Pease, Jr., to the south[34]. The belt of gray-weathering schist and gneiss has been intruded by two large plutons varying in composition from a very coarse grained porphyritic microcline granite to a coarse-grained equigranular diorite. The west-dipping schist and gneiss appear to be right side up on the basis of fair evidence of graded bedding. Only near the intrusive bodies are there reversals of dip.

West of the Monson Border fault and the Bronson Hill anticline in the western part of the Stafford Springs quadrangle (loc. 10), Pease notes that the Bolton syncline at the northern border of Connecticut forms a narrow septum from 3,000 to 5,000 feet wide squeezed between two plutons of Glastonbury Gneiss. The Clough Quartzite maintains a remarkably consistent thickness of 100 to 200 feet on opposite west-dipping limbs for as much as 10 mi along strike. The band of gray schist forming the core of the syncline is 1,000 to 1,500 feet wide north of Crystal Lake. South of the lake the band widens to as much as 3,000 feet.

The general stratigraphic sequence beneath the persistent Clough Quartzite is, from oldest to youngest: Monson Gneiss, Ammonoosuc Volcanics, and rusty schist of the Partridge Formation. Nowhere is the whole sequence complete, and nowhere can it be repeated in mirror image on opposite limbs of the syncline. The Partridge immediately below the unconformity at the base of the Clough is persistent along the west limb of the syncline but is intermittent and too thin to map along most of the east limb. Pease attributes diversities of rock types and sequence along and on opposite limbs of the Bolton syncline largely to abrupt facies changes in a eugeosynclinal environment and partly to unconformity at the base of the Clough Quartzite. No evidence was found for significant tectonic thickening or thinning of rock units.

A study by R. B. Colton of recently completed roadcuts along Route I-84, in the Manchester and Rockville quadrangles, Connecticut (loc. 12), shows that the fault zone along the east edge of the Triassic Lowland is at least 2 mi wide. Within this zone most faults are northeast trending and closely spaced and have small vertical and (or) strike-slip displacement, so that total vertical displacement is distributed among the many faults. Additionally, new large-scale aerial photographs of the area show northeast-trending lineations that offset resistant beds in Box Hill and in the ridge north of Bolton Notch through which a fault zone apparently passes (offsetting rocks on the limbs of the Great Hill syncline).

Tectonic history of the Taconic allochthon in western Vermont

The tectonic and metamorphic history of the north end of the Taconic allochthon in western Vermont (loc. 13) has been revised in light of discoveries made during the past decade in the southern part of the allochthon and elsewhere in the northern Appalachians. According to E-an Zen there were three major episodes of tectonism: (1) Middle Ordovician (Trenton) submarine soft-rock gravity sliding that led to the emplacement of the lower (older) slices of the allochthon. (2) Late Taconic (Late Ordovician to Early Silurian) emplace-

[34] U.S. Geological Survey, 1969, Geological Survey Research 1969, Chapter A: U.S. Geol. Survey Prof. Paper 650-A, p. A23.

ment, as hard rocks, of the higher slices of the allochthon; second generation of westward movement, on a relatively minor scale, of the early slices; development of recumbent folds in the preexisting slices and in the carbonate autochthon and parautochthon (including the Sudbury and Florence nappes and the nappe under Dorset Mountain); formation of slaty cleavage; mild regional metamorphism and whole-rock isotopic clock setting. (3) Acadian (Middle(?) Devonian) refolding, involving formation of small-scale upright to overturned folds in slaty cleavage and in bedding; formation of slip cleavage; a second episode of metamorphism that failed to affect the "slate belt" of the allochthon but increased in grade rapidly from the Vermont Valley eastward. Two other episodes of events that can be deciphered are: a pre-episode-1 event involving high-angle faulting of the carbonate shelf, foundering and flooding of the shelf by mud and graywacke, and uplift to the east that led to the eventual gravity emplacement of the allochthon; and a late Mesozoic(?) event of lamprophyre dike intrusion and subsequent high-angle normal faulting.

Natural gas and uranium in unmetamorphosed rocks of western Vermont

Reevaluation of the geologic and structural data in the Lake Champlain area, western Vermont, by L. R. Page suggests that this area is favorable for finding both uranium and gas deposits. The Gregorie 1 well, drilled through the upper plate of the Champlain thrust east of Mallets Bay (loc. 14), indicates that the dip of the thrust is about 175 feet per mile to the east and that the thrust separates gas-containing unmetamorphosed Ordovician dolomite from an overlying Cambrian dolomite. The Ordovician dolomite has been altered from gray to pink by hydrothermal solutions that have introduced uranium throughout a zone extending northward into Quebec, just east of Phillipsburg. The presence of gas in the Ordovician shales in the above well, the presence of dolomite and other potentially porous reservoir rocks at depth, and the production of commercial gas from Cambrian sandstone at Three Rivers, Quebec, suggest that the area west of the Hinesburg thrust is favorable for prospecting for gas as well as uranium.

Structure and stratigraphy of Massachusetts and northern Connecticut west of the Connecticut River

N. L. Hatch, Jr., working in the Goshen and Woronoco quadrangles, Massachusetts (loc. 15), and S. F. Clark, Jr., working in the Westhampton and Woronoco quadrangles, have mapped a pronounced lithologic break over a strike distance of at least 20 mi that separates rocks of the Goshen Formation on the west from rocks more characteristic of the Waits River Formation of Vermont on the east. Presently available evidence suggests that this boundary is a facies boundary and that the rocks on opposite sides are facies equivalents rather than one being stratigraphically superposed. They have traced this boundary by reconnaissance north to the Northfield-Waits River contact of southern Vermont, where the asymmetry of the Silurian-Devonian metasedimentary units in the Connecticut Valley has long been a source of controversy. Facies changes of the type that they infer in Massachusetts may explain the observed relations in Vermont.

N. L. Hatch, Jr., and R. S. Stanley have continued studies of rocks in the eastern part of western Connecticut probably correlative with the Goshen Formation (Silurian and Devonian) of Massachusetts. They would include in this group most of the rocks previously mapped as Straits Schist, as well as some of the rocks previously mapped as Southington Mountain Schist. Thus they propose a nearly continuous belt of Silurian and Devonian rocks in a series of complex synclines between the Massachusetts–Connecticut State line and Long Island Sound in an area previously interpreted as entirely Ordovician or older, except for the Wepawaug Schist.

S. F. Clark, Jr., has traced three isoclinally folded units of the Goshen Formation northward from the Woronoco quadrangle into the Westhampton quadrangle (loc. 15). A poorly bedded graphitic schist with 1- to 3-foot-thick beds of crumbly weathering calcareous granulite was mapped in the eastern portion of the Westhampton quadrangle. This unit appears to be a facies equivalent of the Goshen quartzite and may be equivalent to the schist of the Conway Formation of Willard.[35]

Mapping by R. W. Schnabel in the West Granville and Tolland Center quadrangles, Massachusetts (loc. 16), has distinguished several lithologic units that are tentatively correlated with the Hoosac Formation of Cambrian age or older. Principal lithologies included in these units are: rusty muscovite schist, locally with trace amounts of graphite; nonrusty quartz-plagioclase-biotite gneiss with only trace amounts of muscovite; nonrusty quartz-plagioclase-muscovite-biotite schist with locally abundant plagioclase porphyroblasts about ¼ inch in diameter, and rare local calc-silicate beds; and nonrusty quartz-plagioclase-muscovite-biotite schist with abundant kyanite or sillimanite nodules and garnet. Many of the lithologic units can be traced several miles, but several pinch out in places, and some are complexly interlayered locally.

The gneisses are lithologically very similar to gneisses exposed to the west and north that have been considered Precambrian.[32] The schists, particularly the schist containing porphyroblastic plagioclase, are lithologically similar to those of the Hoosac Formation of Cambrian age or older exposed to the north. In some exposures the schists and gneisses appear to be conformably interlayered on a scale of 1 to 2 feet. In other exposures the two lithologies appear to be infolded, at least on a local scale. No exposures showing rock with cataclastic texture were found at the contacts, and because evidence for faulting does not exist in the West Granville quadrangle, the

[35] Willard, M. E., 1956, Bedrock geology of the Williamsburg quadrangle, Massachusetts: U.S. Geol. Survey Geol. Quad. Map GQ-85.

entire suite of rocks is tentatively correlated with the Hoosac Formation.

Thrust faulting of lower Paleozoic and Precambrian rocks of the east limb of the Berkshire anticlinorium, western Massachusetts

Intercalated Hoosac Formation rocks of Early Cambrian age or older and rocks of Precambrian(?) age have been mapped by S. A. Norton between Windsor, Mass. (loc. 17), and the Connecticut State line in a zone 25 mi long and 1 mi wide, parallel to the north-trending regional strike. The Hoosac consists of nonrusty to rusty-weathering, medium-coarse-grained aluminous schists. The Precambrian(?) rocks are nonrusty, poorly layered to well-layered two-feldspar-quartz-biotite gneisses with rare muscovite. The gneisses occur in layers ranging from 2 feet to 3,000 feet in thickness; the average thickness is about 200 feet. Individual layers are as much as 5 mi long but thin abruptly, commonly with a 10-percent taper. The contacts between the schist and gneiss are sharp, with no small-scale intercalation or gradation. Steeply east-dipping bedding and foliation in the gneiss and schist are commonly parallel to the contacts; locally the contacts transect bedding at a low angle. The mineralogy at the contacts is consistent with the regional kyanite-to-sillimanite-grade metamorphism. The contacts are deformed by postmetamorphic northeast-plunging left-handed folds and related faults. The favored interpretation of these relationships is a system of premetamorphic or synmetamorphic east-over-west imbricate thrust faults. Less-favored interpretations include interfingering of Hoosac and Precambrian-like sedimentary rocks, and interfolding of the Precambrian rocks and Hoosac Formation.

Post-Middle Ordovician thrusting near Norfolk, Conn.

Mapping by D. S. Harwood in the northwestern part of the Norfolk quadrangle, Connecticut (loc. 18), has shown that the Canaan Mountain Schist of Rodgers and others[36] contains a sequence of mappable units comprised (from oldest to youngest) of (1) finely laminated biotite-muscovite feldspathic metasandstone, (2) coarse garnet-staurolite sillimanite schist, (3) well-bedded feldspathic metasandstone, and (4) garnet-sillimanite-magnetite schist. This sequence is similar in lithology and thickness to one in the Waramaug Formation as used by Rodgers and others[36] in the southwestern part of the quadrangle. The Waramaug rests on Precambrian rocks of the Berkshire Highlands and apparently is the basal Paleozoic unit in the eugeosynclinal sequence. The Canaan Mountain Schist, on the other hand, rests not only on Precambrian rocks but also on Cambrian to Middle Ordovician carbonate rocks in the miogeosynclinal sequence. If the Canaan Mountain Schist is equivalent to the Waramaug Formation, as is suggested by their similar lithologies and stratigraphic sequences, the Canaan Mountain Schist must be thrust over the carbonate rocks of the miogeosynclinal sequence.

[36] Rodgers, John, Gates, R. M., and Rosenfeld, J. L., 1959, Explanatory text for preliminary geological map of Connecticut, 1956: Connecticut Geol. Nat. History Survey Bull. 84, 64 p.

Early Grenville metamorphism in the Berkshire massif, Massachusetts

A coarsely porphyritic perthite-biotite granite gneiss, the Becket Granite Gneiss (formerly the Tyringham Gneiss of Emerson,[37] now abandoned), within the Precambrian gneiss sequence of the Berkshire massif, western Massachusetts, forms a broadly concordant granite-granodiorite sill 1,500 feet thick that intrudes hornblende gneiss, felsic gneiss, and the Washington Gneiss of Emerson, according to N. M. Ratcliffe (r1067) and R. E. Zartman. Microporphyritic granite locally rich in magnetite forms the border of the sill. In the Monterey and East Lee quadrangles (loc. 19) the type Becket and adjacent gneisses are strongly deformed and are in angular unconformity with the overlying Dalton Formation of probable Early Cambrian age.

A concordia plot of U-Th-Pb isotopic data for zircon from the Becket Granite Gneiss and the Washington Gneiss gives the age of both units as approximately 1,060 m.y. This agreement in age between the metasedimentary Washington Gneiss and the metaigneous Becket Granite Gneiss suggests that the zircon in the former and perhaps in the latter unit is of metamorphic origin. This metamorphic and structural event about 1,060 m.y. ago is recognized elsewhere in the Precambrian rocks of the Adirondacks, Green Mountains, and Reading Prong.

ADVANCES IN GEOPHYSICAL TECHNIQUES IN NEW ENGLAND

Truck-mounted magnetometer—a promising new tool

Continuous magnetic profiles, measured by a truck-mounted magnetometer in the New England region, show highly detailed magnetic anomalies which closely reflect the nature and distribution of near-surface bedrock units.

A truck has been outfitted with the basic instruments used in detecting and recording magnetic properties of rocks from the air. Massachusetts and Connecticut were the sites of some of the experimental runs of this truck-mounted unit. Although heavily populated areas with numerous transmission lines; culverts; city sewer, water, and gas pipes; and so forth gave poor results, the rural areas of central and western Massachusetts and northeastern Connecticut provided excellent readings. The various rock units of differing magnetic properties were recorded visually by an irregular line giving a characteristic amplitude and wave length. The magnetic patterns produced

[37] Emerson, B. K., 1898, Geology of old Hampshire County, Massachusetts, comprising Franklin, Hampshire, and Hampden Counties: U.S. Geol. Survey Mon. 29, 790 p.

can help determine the distribution, shape, and attitude of various rock units and structures and may aid in determining the thickness of surficial cover, because anomalies are subdued under thick accumulations of unconsolidated deposits.

The method offers a rapid and versatile way of discriminating igneous and metamorphic bedrock units, a capability which should be especially useful where bedrock exposures are scarce. It could facilitate regional mapping by (1) identifying and approximately locating the contacts of major units before fieldwork begins; (2) locating map units under glacial material during the course of fieldwork; and (3) permitting rapid extension of detailed mapping into surrounding areas after a geologist has determined the magnetic character of each rock unit. The truck-mounted magnetometer provides a closer correspondence of anomalies and map units and more detailed information on the internal complexities and irregularities within rock units than the airbone magnetometer.

Electromagnetic subsurface profiling—a new and promising technique

Electromagnetic subsurface profiling (ESP) is a new and developing method which is being investigated by C. R. Tuttle for the detection of soil and bedrock boundaries. These boundaries are related to the dielectric constant, which is a function of porosity, grain size, conductivity, and moisture content of soil and rock. The equipment and method are being developed by a private consultant at sites suggested by Tuttle, at which subsurface geologic conditions are already known. Comparisons of electromagnetic data with Survey borehole and (or) seismic measurements show that ESP may be able to replace refraction seismic data at sites where bedrock depth is on the order of 10 feet. ESP provides a "photographic" real-time section showing layering, depths, and horizontal positions of lithic units. An interpretation of the time section can be made directly in the field. ESP uses a single antenna which radiates a nanosecond broadband radar pulse into the ground. These pulses penetrate the ground as the antenna is pulled across the surface and are reflected from interfaces between various soil and rock units which have a distinct contrast in dielectric constant. Field tests made in collaboration with C. R. Tuttle have shown (1) the attitude of layered metasedimentary rocks, (2) differentiation of chemically weathered and fresh rock through 4 feet of outcrop, (3) thickness and shape of sand and gravel lenses in glacial sediments, (4) configuration of the bedrock surface concealed by as much as 20 feet of till, and (5) depth through the water table to underlying bedrock. Other potential uses for ESP include detection of cavities in bedrock, determination of snow or ice thickness, and location of buried utility lines.

High detonation pressure sheet-type explosive directs and propagates seismic energy in loose, dry soils

When refraction seismic methods are used to predict subsurface conditions in designing civil structures, dynamite is the common energy source for 12-channel instruments. At best, dynamite has many disadvantages. C. R. Tuttle determined that one prime disadvantage is the rapid dissipation of energy, which results in low-energy compressional first "breaks"—the inflections used to compute subsurface soil thickness and bedrock depth and to obtain velocity from which lithology is identified. In very dry sands and (or) glacial-origin windblown silts containing less than 5 percent moisture, the energy loss (attenuation observed as very low amplitude oscillograph traces) is so severe that dynamite cannot be used. This loss occurs primarily because shotholes are made by hand with a sledge-driven bar, and the holes simply blow out to the surface with charges as large as 2 lb; separating the charge in two holes connected with Primacord improves neither blowout nor efficient energy transfer to the surface recording instruments. The use of a sheet-type explosive with density of 1 g/in^2, oriented vertically and normal to the seismic traverse line, produces clearly visible high-amplitude inflections, not breaks, and permits the method to be used in very dry soils. A piece of 8- by 12-inch sheet-type explosive is fastened to light cardboard with cellophane tape; this backing provides enough rigidity to keep the charge oriented while the shallow vertical slot in the soil which contains the explosive is backfilled and tamped. Detonation is achieved using standard seismic caps. Other shot geometry may favor shear or compressional arrivals. Converted waves may occur.

PLEISTOCENE GEOLOGY

Pleistocene stratigraphy, Cape Cod, Mass.

Mapping in the Hyannis quadrangle (loc. 20), Cape Cod, Mass., by R. N. Oldale has defined a new stratigraphic unit, the Barnstable outwash plain. This unit is nearly equivalent in age to the Mashpee pitted plain to the west and older than the Harwich outwash plain to the east. Evidence for the deformation of the Mashpee pitted plain and the Barnstable outwash plain by a minor readvance of the ice includes push ridges in the moraine and outwash plains and fine-grained lacustrine deposits high up on the south-facing slope of the moraine.

Coastline changes, Monomoy Island, Mass.

Recent changes in the coastline of Monomoy Island (loc. 21), off the southeast elbow of Cape Cod, noted by R. N. Oldale (p. B101–B107)[38] suggest that the island may separate into two parts in 70 or 80 yr. Present encroachment of the south end of the island on two deep basins may result in a major reduction in the southward growth of the spit and possibly increased erosion of the western shore.

Big lake goes down drain—Walpole, Mass.

The stratified glacial deposits of the Medfield quadrangle (loc. 22) and the eastern part of the Holliston quadrangle,

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

eastern Massachusetts, mapped by R. P. Volckmann, were laid down in or graded to a large lake which covered the above area, most of the Norwood quadrangle, and parts of the Brockton and Blue Hills quadrangles to the east. The topset-foreset contacts of glacial deltas in the Medfield and Holliston quadrangles can be matched successfully with postulated outlets in the Brockton and Blue Hills quadrangles. These outlets, which are progressively lower to the north, were uncovered as the ice front melted northward, which caused the lake level to drop in four stages of approximately 10 feet per stage. The final stage, which was approximately 160 feet in elevation, was drained catastrophically when the ice margin moved north of the Blue Hills, exposing the present Neponset River drainage at an elevation of about 50 feet. A deep channel extending from just northeast of the town of Walpole into the Norwood quadrangle was probably cut at the time of the draining of the lake.

Structural evidence for two separate ice advances in New Hampshire

Examination of a recent till cut in Manchester (loc. 23), N.H., by Carl Koteff shows some heretofore unrecognized structural complexity at the contact of two tills thought to be products of two separate ice advances. At many previously studied two-till exposures, a conspicuous sheared zone from a few inches to a half-foot thick has been noted at the contact at the base of the upper till. At the Manchester cut, this zone is also recognized, but here it overlies another structurally deformed zone of principally lower till material, 3 to 5 feet thick. Large pieces of less oxidized, or at least grayer, lower till appear to have been emplaced on top of more oxidized or browner lower till, all of which is truncated by the well-recognized sheared zone of several inches in thickness. It is believed that the structurally deformed zone in the lower till was produced by the last ice sheet bringing up stratigraphically lower old till pieces and emplacing them at the top of the lower till; then ice overrode this system to produce a thinner sheared zone recognized at the base of the upper till.

More on two-till problem, Northfield, Mass.

Grain-size analyses of tills from the Northfield (loc. 24), Mass., N.H., and Vt., quadrangle suggest to K. J. Campbell that the texture of the upper till is mainly controlled by the lithology of the underlying bedrock. The texture of the lower till is relatively consistent throughout the quadrangle and is apparently independent of local bedrock lithology. These relationships probably reflect a difference in mode of deposition and (or) differences in source material for the two-till sheets.

Upper till is three tills, Mount Tom, Mass.

According to F. D. Larsen the results of 21 size analyses indicate that the tills of the Mount Tom (loc. 25) quadrangle, Massachusetts, are closely related to the bedrock provenance in which they are found and that their distance of transport is on the order of 5 to 10 miles. Three tills can be recognized on the basis of color, sand-to-mud ratio, and grouping on a triangular plot of sand, silt, and clay. A reddish-brown till with sand-to-mud ratios less than 1.30 east of the Holyoke Basalt overlies the East Berlin Formation, the Hampden Basalt, and the Portland Arkose. A brownish-red till with sand-to-mud ratios between 2.30 and 4.75 west of the Holyoke Basalt is underlain by the Sugarloaf Formation. A gray till with intermediate sand-to-mud ratios in the northern portion of the Mount Tom quadrangle is believed to be derived from rocks of the crystalline upland. All three tills are presumed to be related to the last major glaciation of New England and to be facies of the "upper" till of southern New England.

A new exposure of Holyoke Basalt has two sets of striae, S. 10° W. and S. 70° W. The S. 10° W. striae are older and parallel the major streamline molded forms produced during maximum glaciation. The S. 70° W. striae prevail on the beveled tops of roche moutonnée forms and are believed to be associated with a readvancing lobe of glacial ice in the Connecticut Valley.

Erosional time scale in western Connecticut

In mapping the surficial geology of parts of Litchfield County (loc. 26), northwestern Connecticut, C. R. Warren (r1072) has found that bedrock valleys in that area (other than those carved in marble) fall naturally into four groups according to their apparent degree of geomorphic development. Most valleys look relatively old and are evidently of preglacial origin: these were carved in a period of several million years. A few valleys, however, are narrow, steep-sided gorges that contrast with the older valleys. Two of the gorges are more than 150 feet deep and probably took between 500,000 and 1,000,000 yr to carve. The rest of the gorges are less than 50 feet deep and were probably carved within the last 100,000 to 200,000 yr. Valleys where streams have been flowing only since the latest ice age (less than 15,000 yr ago) are scarcely notched into the rock at all.

Glacial Lake Sheffield, Ashley Falls area, Massachusetts and Connecticut

Mapping in the Ashley Falls area, western Massachusetts and Connecticut, by the late G. W. Holmes and W. S. Newman has shown that the upper Housatonic River valley was partially filled by glacial Lake Sheffield in late glacial time. The lake's boundaries, delineated by strandlines and by silt and fine sand in borings, extended north from a 650-foot rock threshold at Great Falls near Falls Village (loc. 27), Conn., for a distance of about 20 mi to Great Barrington, Mass. Strandline sediments can be traced from the South Caanan quadrangle into the Ashley Falls quadrangle over a distance of almost 4 mi, rising about 20 feet within this interval. A tilt ratio of approximately

5 feet per mile here compares well with those farther east in New England but differs from the 2.2 to 3.6 rates reported from the Hudson Valley. The tilt ratio might be at least in part a function of stagnant ice persistence in valleys—the longer the ice lingered, the lower the tilt ratio.

Alluvial fans, mostly of late glacial age but some still accumulating, occur with some regularity where streams undergo rapid gradient decreases at the foot of steep slopes. Several of these fans should prove important sources of sand and gravel, particularly at Salisbury and Wangum Lake Brook in northwestern Connecticut.

Deglaciation, Kent, Conn.

Interesting aspects of deglaciation associated with melt-water channels in the Kent and Ellsworth quadrangles, western Connecticut (loc. 28), have been worked out by G. C. Kelley. Local marginal positions of weak, active ice have been identified where overflow or outlet channels are incised in till and bedrock ridges. Other marginal positions are indicated by boulder and cobble concentrations associated with abandoned channels hanging on slopes. Successive deglaciation of upland ridges was slow, permitting adjacent, isolated stagnating ice-mass surfaces to melt lower. These lower surfaces received sediment-laden melt waters issuing from higher, receding ice. On the broad ridges, melt waters coalesced into integrated drainage patterns recognized today where related channels are abandoned or now contain underfit streams. Late glaciofluvial activity in the northwestern part of this region near Sharon, Conn., consisted of a large abandoned melt-water channel, its tributaries, and related deposits. Final phases in the Housatonic River valley consisted of stream deposition of low-elevation valley-train materials.

Numerous swampy areas are evident in this region. While Holocene accumulation of organic material is mostly shallow, some deposits exceed 25 feet. Careful evaluation of bogs and fens is recommended before they are utilized either commercially for their organic material or by residents for developing ponds.

Preglacial drainage, Danbury—New Milford area, Connecticut

Preliminary analysis of subsurface data in the Still River valley by Fred Pessl, Jr., Danbury and New Milford quadrangles, Connecticut (loc. 29), indicates that the preglacial drainage was north, rather than south as had previously been proposed. Glaciation resulted primarily in local overdeepening of the bedrock and the development of a long, narrow proglacial lake which extended from the Bethel-Danbury area north to the vicinity of New Milford, Conn. This distribution, together with elevations of deltas associated with ice-contact deposits and lake-bottom sediments, defines several lake levels ranging in elevation from more than 450 feet in the southern part of the valley to about 290 feet in the northern part. Outlets which acted as spillways draining the ponded melt water east into the Housatonic River have been identified at 370 feet elevation on the east side of the Still River valley near Danbury, and at 290 to 300 feet elevation near Lanesville, Conn. Spillways for the higher levels of the glacial lake have not yet been determined.

APPALACHIAN HIGHLANDS AND THE COASTAL PLAINS

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Folds and lineaments, St. Lawrence County, N.Y.

Mapping by C. E. Brown in connection with mineral-resource investigations of Grenville metasedimentary rocks infolded into amphibolitic and granitic gneisses in the western part of St. Lawrence County, N.Y. (locality 1, index map), shows that the northeast nose of the recumbent Beaver Creek anticline has a strong lineation plunging steeply northwest and alined with the axes of a complex set of cross-folds.

The Beaver Creek anticline is bounded on the northwest by a conspicuous topographic lineament, the valley of Beaver Creek about 20 mi long. Structural style and stratigraphy change abruptly across this lineament. A similar topographic lineament lies 1 to 2 mi to the northwest. The lineaments appear to separate the area into elongate geologically distinct blocks and are interpreted as the sites of wrench faults that were active slightly before or penecontemporaneously with the metamorphism of the Grenville Series. Pegmatites are numerous along each of these lineaments.

APPALACHIAN PLATEAUS AND THE VALLEY AND RIDGE PROVINCES

Geologic investigations in the Appalachian Plateaus and Valley and Ridge provinces have led to insights into geologic processes of great benefit both economically and scientifically. Typical of such mapping projects are the following: L. D. Harris' study of the Knox Group in east Tennessee suggests that porous stromatolite reefs are potential targets for oil and gas exploration. The structural and stratigraphic studies of J. B. Epstein and A. A. Drake, Jr., in northeastern Pennsylvania have increased our understanding of the rocks of the "Taconic belt" and of the geologic relationship of the rocks of the Valley and Ridge province to those of the Blue Ridge and Piedmont provinces. Knowledge of the extent and nature of the coal measures is continually being enlarged as a result of mapping by G. H. Wood, Jr., Wallace de Witt, Jr., K. J. Englund, and others. Depositional environments are being investigated by A. G. Epstein, J. B. Epstein, L. D. Harris, and Wallace de Witt, Jr.

Stromatolite reefs in lower Paleozoic rocks of eastern Tennessee and southwestern Virginia

L. D. Harris has shown that algal stromatolite reefs form a substantial part of the Copper Ridge Dolomite and the Chepultepec Dolomite of the Knox Group of Late Cambrian and Early Ordovician age (loc. 2). Basin analyses indicate that these reefs are widespread and almost continuous in the lower part of the Copper Ridge but are isolated masses in the upper Copper Ridge and lower Chepultepec. Facies diagrams suggest that the reef complexes developed in shallow subtidal to low intertidal environments. The reefs are composed of digitate algal stromatolites that contain channel fills and interbeds of oolitic dolomite and intraclasts of fine- to medium-crystalline, brownish-gray dolomite. The dolomite contains many openings or vugs and, when freshly broken, emits a strong petroliferous odor. The presence of vugs in algal stromatolite zones from drill cuttings and cores from Lee County, Va. (L. S. Bales well), and Pickett County, Tenn. (A. Sell well), demonstrates that the vugular character of the reefs persists into the subsurface. Widespread algal stromatolite reefs with such a high porosity are potential future targets for oil and gas exploration in the southeastern United States.

Studies on cleavage, northeastern Pennsylvania

Field relations and microscopic studies by J. B. Epstein (r0419) in the Stroudsburg area, Northampton and Monroe Counties, Pa., suggest that the regional cleavage in rocks of Middle Ordovician to Early Devonian age (loc. 3) is due to laminar flow of pelitic material along cleavage folia. This flow was accompanied by mechanical reorientation of platy and elongate minerals and new growth of mica, quartz, chlorite, and possibly albite. Porphyroblasts of chlorite and muscovite appear to have grown in low-pressure interfolial areas by (1) isolation of the potential porphyroblast area by surrounding cleavage folia, (2) slight mechanical reorientation (crenulation) of the platy minerals that originally paralleled bedding fissility, and (3) recrystallization and growth in size of crystals. Numerous lines of evidence point to the conclusion that cleavage developed after the rock was indurated at, and just below, conditions of low-grade metamorphism. Intensity of cleavage development increases to the southeast across the area. Second-generation crenulation cleavage formed by mechanical reorientation of minerals as well as by limited new mineral growth.

Detailed mapping by A. A. Drake, Jr., to the southeast in the Allentown East and Catasauqua quadrangles, Northampton and Lehigh Counties, Pa. (loc. 3), has shown that in addition to slaty cleavage (S_1) and crenulation cleavage (S_3), and their associated folds and lineations, there is a third set of fabric elements of intermediate age (S_2)[39,40]. This set is a poor fracture cleavage, which is parallel to axial surfaces of folds in slaty cleavage (S_1) and bedding and forms a crenulation (intersection) lineation on slaty cleavage that plunges either northwest or southeast depending on the dip of the slaty cleavage. The strike of this cleavage (S_2) and its associated folds and lineations roughly parallels the regional tectonic transport direction and may not have been previously recognized because it also more or less parallels the *a* smear on slaty cleavage. The fabric elements of S_2 are cut by the later crenulation cleavage (S_3) and its associated linear elements. Folds of S_2 are numerous in carbonate rocks in the Allentown East quadrangle, and in many places S_2 cleavage is the only one present. It is also present within the Precambrian terrane. Some steep cross faults (thrusts) are about parallel to the cleavage. This set of fabric elements seems to have formed within a $b \perp b'$ stress field. Neither the areal extent nor the activation mechanism is known at this time, but the set may have been the result of either overriding by the Hamburg klippe or flow within the lower limb of the Musconetcong nappe owing to convergence in *b* because of irregular competent highs in the underlying Lyon Station–Paulins Kill nappe.[41]

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[39] Drake, A. A., Jr., 1969, Precambrian and lower Paleozoic geology of the Delaware Valley, *in* Subitsky, Seymour, ed., Geology of selected areas in New Jersey and eastern Pennsylvania: New Brunswick, Rutgers Univ. Press, p. 51–131.

[40] Drake, A. A., Jr., 1970, Structural geology of the Reading Prong, *in* Fisher, G. W., Pettijohn, F. J., Reed, J. C., Jr., and Weaver, Kenneth, eds., Studies of Appalachian geology–central and southern: New York, Interscience Pub., p. 271–291.

[41] U.S. Geological Survey, 1969, Geological Survey Research 1969, Chapter A: U.S. Geol. Survey Prof. Paper 650-A, p. A28.

Overthrust belt, northeastern Pennsylvania and New Jersey

Lenticular masses of Jacksonburg Limestone (Middle Ordovician) and Epler Formation (Lower Ordovician) were found in Allentown Dolomite (Upper Cambrian) by A. A. Drake, Jr., along the axial area of the Ackerman anticline[42] in the fault-bounded Paulins Kill valley, northeastern New Jersey (loc. 4). The carbonate rocks of the valley are thought to be in the upper limb of the largely buried Lyon Station–Paulins Kill nappe,[41] which to the southwest is cored by Precambrian rocks, at least from Lyon Station, Pa., to Bangor, Pa., as indicated by aeromagnetic surveys. The Jacksonburg and Epler are relatively undeformed along the bounding fault, but they are severely deformed in the axial area in cores of overturned upward-closing folds, the northwest limbs of which are sheared out. It appears, therefore, that the Ackerman anticline in New Jersey is an antiformal refold similar to those in the Musconetcong nappe.[40] The severely deformed Jacksonburg and Epler are in the overturned limb of the Lyon Station–Paulins Kill nappe, exposed by arching and faulting of the original recumbent fold; the simpler appearing Ackerman anticline to the southwest reflects the arching of the upright upper limb. No Precambrian rocks are exposed in the core of the nappe in New Jersey.

Recent reconnaissance by A. A. Drake, Jr., and J. B. Epstein in Northampton, Lehigh, and Berks Counties, Pa. (loc. 5), has shown that clastic sedimentary rocks mapped as Martinsburg Formation west of the Lehigh River differ from the Martinsburg Formation of the Pennsylvania slate belt. The former rocks, the fossiliferous Shochary Sandstone of Willard,[43] and the related interbedded pelite, graywacke, and calcisiltite are the host for exotic allochthonous rocks which make up what has been called the Hamburg klippe, consisting of red and green pelite, limestone conglomerate, limestone, quartz-pebble conglomerate, quartzite, polymictic wildflysch, and wildflyschen. The exotic rocks have many characteristics of emplacement by submarine sliding with the probability that several slides are involved. The host rocks for the slide deposits, however, are in tectonic contact with the Martinsburg Formation and older carbonate rocks of the Musconetcong nappe of the Delaware and Lehigh Valleys. The northern contact is the Eckville fault of Behre,[44] and the eastern limit is marked by stacked recumbent folds in a fringe of the Bushkill Member of the Martinsburg along the high ground of the Trexler-Lehigh County Game Preserve. The southern and western limits are not well defined yet. It is likely that much if not all of the rock mapped as Martinsburg as far west as the Susquehanna River belongs to the "western Martinsburg," as exotic slide blocks are numerous throughout that terrane. If this is so, the contact between "western Martinsburg" and slate belt Martinsburg in Lehigh County separates major tectonic units. The Hamburg klippe, therefore, represents two events: submarine emplacement of exotic rocks into a host of interbedded pelite and graywacke, and the subsequent transport of both host and guest to their current position by hard-rock thrusting.

In the Slatesdale and Topton quadrangles, in this same area, A. A. Drake, Jr., found small limestone clasts and slide blocks, which are identical with those of the Epler Formation (Beekmantown Group, Lower Ordovician), within wildflysch of the allochthonous sequence of the so-called Hamburg klippe. The clasts and blocks have a deformation fabric that is similar to the fabric in limestones in the Musconetcong nappe;[40] that is, a tectonic layering produced by the transposition of bedding. In some specimens, hinges are tucked in between the layering, and layering surfaces are marked by a strong ruling lineation which plunges down the dip. The clasts obviously were deformed prior to their deposition in the wildflysch, as the tectonic layering is not parallel to cleavage in the matrix. Thus, severe deformation preceded wildflysch deposition. This relation suggests that the Taconic orogeny began southeast of the present exposure of these rocks and that the wildflysch heralded the arrival of the orogeny.

Coal and flint-clay resources in Bedford County, Pa.

A small area in the Wellersburg syncline west of Gooseberry Run and north of Wills Creek in the Fairhope 7½-minute quadrangle, Bedford County, Pa. (loc. 6), mapped by Wallace de Witt, Jr., is underlain by rocks of the Lower Kittanning coal zone.[45] According to de Witt, the Lower Kittanning coal zone in southwest Bedford County contains a coalbed, as much as 4 feet thick, associated with lenses of brown and brownish-gray flint clay interbedded in silty soft clay or clayey siltstone. X-ray analysis indicates that the flint clay is of high grade but is locally contaminated by grains and nodules of siderite. Coal and clay were mined from the Lower Kittanning coal zone at the now abandoned New England mines 1 mi north of Hoblitzell on the west side of Gooseberry Run, thus reducing the area that may contain recoverable coal or clay in the Lower Kittanning zone in southwest Bedford County. The Mount Savage–Clarion coal zone, which contained large amounts of high- and medium-grade flint clay at Williams in Somerset County west of Hoblitzell, does not appear to be present along Gooseberry Run.

Pocono-Catskill unconformity in Pennsylvania Anthracite region

An angular unconformity between the Pocono and Catskill Formations in the western part of the Pennsylvania Anthracite

[42] Drake, A. A., Jr., Epstein, J. B., and Aaron, J. M., 1969, Geologic map and sections of parts of the Portland and Belvidere quadrangles, New Jersey-Pennsylvania: U.S. Geol. Survey Misc. Geol. Inv. Map I-552.

[43] Willard, Bradford, 1943, Ordovician clastic sedimentary rocks in Pennsylvania: Geol. Soc. America Bull., v. 54, no. 8, p. 1067–1121.

[44] Behre, C. H., Jr., 1933, Slate in Pennsylvania: Pennsylvania Geol. Survey, 4th ser., Bull. M-16, 400 p.

[45] Waage, K. M., 1949, Stratigraphy of Georges Creek Coal Basin, *in* Tonges, A. L., and others, 1949, Investigation of lower coal beds in Georges Creek and north part of Upper Potomac basins, Allegany and Garrett Counties, Md.: U.S. Bur. Mines Tech. Paper 725, p. 19–28.

region was described about 10 yr ago by J. P. Trexler, G. H. Wood, Jr., and H. H. Arndt.[46,47] Subsequent work by Harry Klemic, J.C. Warman, and A.R. Taylor[48] and by W.D. Sevon[49] did not recognize the unconformity in the eastern part of the region, and D. M. Hoskins[50] has argued against its existence. In 1970 Sevon and Wood studied the Pocono-Catskill rocks in the Tamaqua and Nesquehoning 7½-minute quadrangles in the eastern part of the Anthracite region (loc. 7). They found that the unconformity cuts irregularly into the upper part of the Catskill Formation in these quadrangles and that the lower member of the Pocono Formation as recognized by Sevon[49] and by Klemic and others[48] was the Spechty Kopf Member of the Catskill as defined by Trexler and others[47]. Wood believes that the recognition of the unconformity throughout the southern part of the region and reassignment of the rocks below the unconformity to the Catskill should end the arguments that have persisted for 50 yr over the Pocono-Catskill contact.

Cumberland overthrust sheet, southwest Virginia

Stratigraphic studies of Carboniferous rocks in Buchanan and Dickenson Counties, southwest Virginia (loc. 8), by K. J. Englund (p. B13–B16) show approximately 4 mi of strike-slip movement along the Russell Fork fault at the northeast edge of the Cumberland overthrust sheet. This determination of northwest movement was based on the displacement of isopachs of the northwestward-thinning Pocahontas Formation and adjacent strata. Previous estimates, basis unspecified, suggested about 2 mi of movement along this fault.

Paleoenvironmental and facies studies, northeastern Pennsylvania

Conodonts collected by A. G. Epstein from the Coeymans and lower New Scotland Formations in Monroe County, Pa., and their correlatives in Sussex County, N.J., and Orange County, N.Y. (loc. 9), that were studied by A. G. Epstein and J. B. Epstein, include 21 form genera, referrable to 40 form species. *Spathognathodus remscheidensis* Ziegler and *Ozarkodina typica denckmanni* Ziegler are the most abundant species. Index fossils of the lower Gedinnian *woschmidti* zone (*Spathognathodus remscheidensis* Ziegler, *Lonchodina cristagalli* Ziegler, and *Icriodus woschmidti woschmidti*) occur in the lower Coeymans. The persistence of abundant specimens of *Icriodus woschmidti woschmidti* from the upper Peters Valley Member through the Stormville Member of the Coeymans Formation without appearance of other icriodiform elements (except a rare specimen of *I. w.* ssp. cf. *I. w. postwoschmidti* Mashkova) indicates an early Gedinnian age for these beds on the basis of icriodiform elements known in lowermost Devonian rocks in Podolia, U.S.S.R., and in Spain. Rare specimens of *I. w. woschmidti* from the Thacher Member of the Manlius Formation in New Jersey indicate that this unit is also of early Gedinnian age.

The abundance and diversity of the conodonts are related to the environment of deposition. Conodonts are most abundant and diverse in open-shelf shallow neritic calcisiltite to calcarenite facies and decrease in abundance and diversity both landward and seaward of this environment. Conodonts decrease in abundance with increase in terrigenous content of the enclosing rock.

A 12- to 14-foot laminated and mud-cracked dolomite and fossiliferous (ostracode-rich) intraclastic stromatolitic fine-grained limestone between the Bossardville Limestone and Decker Formation (Upper Silurian) is recognized by J. B. Epstein in the Stroudsburg–Saylorsburg area, Monroe County, Pa. (loc. 3). A similar unit has been traced in scattered exposures northeastward into southeasternmost New York,[51] where dolomite, limestone, shale, and sandstone called at different times Accord Shale (of Fisher[52]), Binnewater Sandstone (of Hartnagel[53]), and Poxono Island Formation appear to be a tongue of Poxono Island extending southwest over the Bossardville of Pennsylvania. The Poxono Island Formation underlies the Bossardville Limestone in eastern Pennsylvania, but the Bossardville pinches out in southeastern New York. The dolomite-bearing unit is interpreted as having formed on a supratidal mudflat and represents a regional regressive impulse or slowing down of a mostly oscillating transgression during late Silurian and Early Devonian time.

THE BLUE RIDGE AND PIEDMONT

Geologic investigations in the Blue Ridge and Piedmont have largely been confined to the Piedmont of Maryland and northeastern Virginia and to the slate belt of the central North Carolina Piedmont. Considerable progress has been made in

[46] Trexler, J. P., Wood, G. H., Jr., and Arndt, H. H., 1961, Angular unconformity separates Catskill and Pocono Formations in western part of the Anthracite region, Pennsylvania: Art. 38 *in* U.S. Geol. Survey Prof. Paper 424-B, p. B84–B88.

[47] Trexler, J. P., Wood, G. H., Jr., and Arndt, H. H., 1962, Uppermost Devonian and Lower Mississippian rocks of the western part of the Anthracite region of eastern Pennsylvania: Art. 73 *in* U.S. Geol. Survey Prof. Paper 450-C, p. C36–C39.

[48] Klemic, Harry, Warman, J. C., and Taylor, A. R., 1963, Geology and uranium occurrences of the northern half of the Lehighton quadrangle, Pennsylvania and adjoining areas: U.S. Geol. Survey Bull. 1138, 97 p.

[49] Sevon, W. D., 1969, The Pocono Formation in northeastern Pennsylvania, *in* Guidebook for 34th Annual Field Conference of Pennsylvania Geologists: Pennsylvania Geol. Survey, 129 p.

[50] Hoskins, D. M., 1970, Alternative interpretation of the Catskill-Pocono contact in the Anthracite area of Pennsylvania [abs.]: Geol. Soc. America Abs. with Programs, v. 2, no. 1, p. 25.

[51] Epstein, A. G., Epstein, J. B., Spink, W. J., and Jennings, D. S., 1967, Upper Silurian and Lower Devonian stratigraphy of northeastern Pennsylvania, New Jersey, and southeasternmost New York: U.S. Geol. Survey Bull. 1243, 74 p.

[52] Fisher, D. W., 1960, Correlation of the Silurian rocks in New York State: New York State Mus. and Sci. Service Map and Chart Ser. No. 1.

[53] Hartnagel, C. A., 1905, Notes on the Siluric or Ontaric section of eastern New York: New York State Mus. Bull. 80, p. 342–358.

unravelling the complex stratigraphy of the slate belt rocks in North Carolina and northeast Virginia. Stratigraphic studies and new radiometric age determinations in the Blue Ridge and Piedmont have helped to fix with more certainty the age of these rocks as late Precambrian to Cambrian. In addition, the data indicate the relative abundance of rock units of Grenville age in the Piedmont and Blue Ridge. Investigations in connection with the mapping of the Blue Ridge and Piedmont of North Carolina and Virginia (Winston-Salem 2° quadrangle) have more firmly established the relative age, nature, and distribution of the Precambrian and lower Paleozoic rocks in that area.

Geophysical studies in the southern Piedmont have greatly aided in discerning the distribution of rock types, shape of plutonic masses, and delineation of structural features in areas where exposures are poor and soil cover thick. Road magnetometer traverses in the slate belt area have been quite useful in delineating unit boundaries and locating dikes.

Stratigraphy in the Maryland Piedmont

Stratigraphic and structural studies by G. W. Fisher in the New Windsor quadrangle, Carroll County, Md. (loc. 10), have produced new evidence for interpreting the relationship of the Glenarm Series of the Maryland Piedmont with the rocks of the folded Appalachians to the west. The rocks of the New Windsor area include (1) an eastern facies of clean dolomitic marble containing oolites and stromatolites that was deposited in shallow water and lies stratigraphically above a thick pile of metabasalts; and (2) a western facies of deeper water argillaceous limestone associated with chloritic phyllites, probably tuffaceous in part. These two facies overlie a persistent quartzite zone, which in turn overlies muscovite-chlorite phyllite which grades eastward into the Wissahickon Formation of the Piedmont. The quartzites and phyllites may represent the upper part of the Lower Cambrian clastic sequence of the folded Appalachians; if so, many of the Piedmont rocks are probably eugeosynclinal equivalents of the Cambrian and (or) Ordovician rocks of the miogeosynclinal belt of the folded Appalachians.

In the Maryland Piedmont, according to M. W. Higgins, the Port Deposit Gneiss (metamorphosed granodiorite), of Cecil County, Md. (loc. 11), the small body of granodiorite near Elkton, Md., and several other plutons associated with metavolcanic rocks give zircon Pb/U ages that plot on the same 540- to 560-m.y. chord on a concordia diagram as the zircons from the metavolcanic rocks. Field relations suggest that these are shallow plutons that supplied the volcanic rocks (M. W. Higgins, r0902). Locally, these shallow plutons intruded their own cover of volcanic rocks. Interbedding of rocks of the Wissahickon Formation with metavolcanic and metavolcaniclastic rocks of the James Run Formation suggests that the volcanic rocks are contemporaneous with the Wissahickon. This indicates that most of the Wissahickon is Early Cambrian in age and probably correlative with the Chilhowee Group.

Structural, stratigraphic, sedimentologic, and geophysical evidence suggests to M. W. Higgins (r1268) that the Peach Bottom fold (Peach Bottom "syncline") in northeastern Maryland and southern Pennsylvania is an anticline. The Peach Bottom Slate and Cardiff Metaconglomerate are probably correlative with the lower part of the Hellam Member of the Chickies Formation. The quartzite facies of the Wissahickon (formerly Peters Creek Quartzite) is correlative with the upper part of the Chickies Formation.

Quantico syncline

Geologic mapping by V. M. Seiders and R. B. Mixon in the Occoquan and Belvoir quadrangles, Prince William and Fairfax Counties, Va. (loc. 12), has shown that the Quantico syncline is locally inverted. The syncline, composed of Quantico Slate (Ordovician (?)) and underlying Cambrian metavolcanic rocks, trends northeast and has steeply dipping limbs. Southwest of Occoquan Creek the syncline is upright and plunges southwest. To the northeast, the areal distribution of the stratigraphic units and the attitude of abundant graded beds show that the axis of the syncline steepens and becomes inverted, forming an antiform whose axis plunges moderately to the northeast. A northwest-trending fault offsets the syncline just southwest of Occoquan Creek. Both the fault and the syncline are cut by a discordant granite pluton. Work is in progress to date zircons from the granite and thus establish limits on the age of tectonism and plutonism.

Blue Ridge and inner Piedmont of North Carolina and Virginia

A major new stratigraphic unit of gneiss, metapelite, and amphibolite with minor amounts of quartzite and marble has been mapped by D. W. Rankin, G. H. Espenshade, and K. W. Shaw on the Blue Ridge Escarpment from Wilkes County, N.C., to Patrick County, Va. (loc. 13). The gneiss typically shows quartzo-feldspathic laminae separated by micaceous partings giving a pinstripe appearance; some pelitic rocks are graphitic. These rocks, which were metamorphosed in the middle Paleozoic, form a belt 15 mi wide southeast of and stratigraphically above the Ashe Formation (Precambrian) in its type area. Southeast of the laminated gneiss unit is another belt of Ashe which overlies older Precambrian granitic gneiss of the core of the Sauratown Mountains anticlinorium. The Precambrian age of this granitic gneiss has recently been confirmed by T. W. Stern (D. W. Rankin and others, r1275). Zircons from granitic gneiss in a quarry at Pilot Mountain, N.C., yield Pb/Pb ages of about 1,190 m.y. Thus, in gross structure, the laminated gneiss unit appears to occupy the trough of a major synclinorium; the older Precambrian granitic gneiss crops out on opposite limbs 30 mi apart. The synclinorium is dextrally en echelon to the James River synclinorium of central Virginia. Despite the apparent structural offset, the laminated gneiss unit should correlate in part with the Evington Group of the James River synclinorium.

The contact between the southeastern belt of Ashe and the laminated gneiss unit is a fault that extends for more than 100 mi across the Winston-Salem 2° quadrangle, from the Brevard fault zone near Patterson, N.C., northeast to a fault zone at Fairy Stone State Park, Va., that contains the Bowens Creek fault mapped by Conley and Henika.[54]

A complex of mica schist and gneiss, amphibolite, and intrusive granitic and mafic rocks near Winston-Salem, N.C. (loc. 14), mapped by G. H. Espenshade, overlies the southern flank of the Precambrian core of the Sauratown Mountains anticlinorium. The pattern of lithologic units in this area, 40 mi long and 10 to 20 mi wide, is now rather well known, but stratigraphic and structural relations are not so clear. Directly above the basement rocks are south-dipping schist, biotite gneiss, and amphibolite of the Ashe Formation(?) in the kyanite-staurolite zone that form a crescentic belt extending east from the southwest nose of the anticlinorium for 30 mi to the Dan River Triassic basin. Henderson Gneiss overlies the Ashe in a belt as much as 3 mi wide that extends eastward along the anticlinorium for 25 mi. This belt of Henderson also flanks the southeastern side of the Brevard fault zone for more than 50 mi southwest from the anticlinorium and is associated with sillimanite-grade schists and synorogenic granite in the Inner Piedmont belt. Lithologic and structural patterns suggest that this inner Piedmont complex is overthrust to the north against both the Brevard zone and the Sauratown Mountains anticlinorium. Biotite gneiss and gneissic granite, probably of the inner Piedmont belt, extend to the east edge of the Winston-Salem quadrangle. South of this belt is a complex of granite and metagabbro that appears to be the northern part of the Charlotte belt. Relations between the rocks of the inner Piedmont and Charlotte belts near Winston-Salem are not yet understood.

Ages of Carolina slate belt rocks

Zircon U-Pb isotope dating by A. K. Sinha (r1392) in cooperation with Lynn Glover III, M. W. Higgins, S. R. Hart, G. L. Davis, and W. S. Kirk, has established that the granodiorite at Roxboro, Virgilina district, Person County, N.C. (loc. 15), is between 573 and 620 m.y. old (Precambrian Z to earliest Cambrian). Because the granodiorite intrudes the entire outcropping sequence in the Carolina slate belt in this area, the younger age limit of the slate belt must be in this same range. Three samples from the top of the lower felsic pyroclastic unit (Hyco Quartz Porphyry of F. B. Laney[55]) have Pb/Pb ages of 607, 618, and 636 m.y. with a chord-concordia intersection age of 620 m.y. (Precambrian Z).

West of the Virgilina district, the low metamorphic grade Hyco rests with apparent stratigraphic conformity on higher grade mafic and felsic gneisses of probable volcanic parentage in the adjacent Charlotte belt. Zircon samples taken near the oldest outcropping part of this gneiss sequence yield Pb/Pb ages of 352, 436, 439, 441, and 685 m.y. with a chord-concordia intersection age of about 740 m.y., according to Lynn Glover (r1264), A. K. Sinha, M. W. Higgins, and W. S. Kirk. This evidence and other studies suggest a Precambrian Z birth for the Appalachian geosyncline and, in this area, an episode of folding during Precambrian Z or earliest Paleozoic.

Petrography of Carolina slate belt rocks, North Carolina

Petrographic study by J. B. Hadley of the more mafic rocks of an intrusive complex in the lower part of the slate belt sequence, Oxford quadrangle, Granville County, N.C. (loc. 16), indicates an association of gabbroic and dioritic rocks with compositional grading resulting from variations in the water content of the crystallizing magma. The driest magma yielded ophitic to subophitic pyroxene gabbro. Successive increases in water content during later stages of crystallization yielded: hornblende gabbro with texture similar to that of the pyroxene gabbro but strongly zoned plagioclase and hornblende pseudomorphs after partly or wholly replaced pyroxene; hornblende diorite with less than 5 percent quartz and highly saussuritized plagioclase enclosed in albite-oligoclase rims; and hornblende-quartz diorite with 5 to 12 percent quartz, relict ophitic texture with quartz molded between hornblende and sodic plagioclase, and pegmatitic pockets.

The quartz content is approximately proportional to the alteration of calcic plagioclase to epidote and micas, reactions which yield silica. It appears, therefore, that the alteration took place before final consolidation of the rocks and provided much of the silica to form the late-crystallizing quartz. Late, fine-grained phases of the hornblende diorite contain abundant phenocrysts of hornblende, showing that enough water was present in these rocks to form early hornblende rather than pyroxene.

Geophysical studies in the Carolina slate belt

Magnetic analysis by D. L. Daniels of greenschist facies metasedimentary and metavolcanic rocks in the Carolina slate belt, Saluda County, western South Carolina (loc. 17), shows that well-foliated metavolcanic rocks of intermediate silica content are anomaly-producing rocks. Greenstones and meta-argillites are consistently nonmagnetic. Some metasedimentary rocks, especially those clearly containing volcanic debris, are also magnetic. The magnetite in these rocks is not relict but is a metamorphic phase which is most abundant in rocks high in K_2O and low in CaO content.

Daniels observes that the comparison of aeromagnetic data, obtained by low-level flying, with structural data suggests that aeromagnetic maps can be used for a quick indication of tectonic style in metamorphic terrane. Areas of tight folding

[54] Conley, J. F., and Henika, W. S., 1970, Geology of the Philpott Reservoir quadrangle, Virginia: Virginia Div. Mineral Resources Rept. Inv. 22, 46 p.

[55] Laney, F. B., 1917, The geology and ore deposits of the Virgilina district of Virginia and North Carolina: North Carolina Geol. Survey Bull. 26, 176 p.

about horizontal fold axes and steep axial planes have long linear anomalies of short wave length that are parallel to the regional grain. In contrast, recumbent folds produce low-amplitude arcuate anomalies.

Geophysical mapping by Peter Popenoe around the Haile, Brewer, and Blackmon gold mines, Lancaster, Chesterfield, Kershaw, Lee, and Custer Counties, S.C. (loc. 18), shows that mineralization may be strongly influenced by structural controls. Both the Haile and Blackmon mines lie along an unusual concentration of northwest-trending diabase dikes of Triassic(?) age which may be easily traced by their aeromagnetic and ground magnetic expression. At least 16 dikes are found within a 3-mile radius of the Blackmon mine, and approximately the same number are found within a 3-mile radius of the Haile Mine. One continuous dike cuts through the center of both mine pits, which are more than 6 mi apart. This evidence, along with northwest-trending zones of sericitized and altered slate belt rocks, northwest zones of mineralization, and topographic lineations, shows that both mines probably lie on an ancient zone of weakness transverse to the Appalachian trends into which mineral solutions penetrated and the Triassic dikes were intruded. The coincidence of this zone with a major belt of earthquake epicenters which parallels the dikes and extends to Charleston, S.C., suggests that the mine areas may occupy a boundary position between two major crustal blocks.

Relationship of soils and geophysical patterns to bedrock, central North Carolina

Geologic investigations in the Salisbury 15-minute quadrangle, Davidson, Rowan, Randolph, Montgomery, and Cabarrus Counties, N.C. (loc. 19), are difficult because outcrops of bedrock and of saprolite are scarce and rock float is uncommon, particularly in the area west of the Gold Hill fault. Mapping by A. A. Stromquist is based primarily on the interpretation of geophysical patterns on aeromagnetic-radiometric maps and on the character of the soils.

Quartz monzonite is indicated by grayish sandy to silty soils, aeromagnetic lows, and depression contours. Green schists and sericitic schists, largely intruded by a gabbro-diorite complex, form red-brown clay loam soils and reflect magnetic highs. Reddish soils from metamorphic rocks with some felsic and mafic intrusions and dikes reflect moderately low magnetic contours. Reddish "dry" soils containing tiny cusps of pale mica and, locally, large feldspar porphyroblasts suggestive of thermodynamic metamorphism also reflect magnetic lows and depression contours. Diabase dikes only inches wide can be traced for miles from the pattern of magnetic contours they produce. These dikes commonly parallel a regional northwest-trending joint pattern.

The radiometric contours verify the above interpretations. In areas of relatively abundant outcrop, the radiometric contours outline mapped mafic rock units fairly accurately.

COASTAL PLAINS

Quaternary formations on the Delmarva peninsula

Four mappable post-Miocene units have been recognized in the southern part of the Delmarva peninsula of Delaware, Maryland, and Virginia (loc. 20), according to J. P. Owens. Three of these units are marine, while the fourth is nonmarine. The nonmarine unit is largely channel-fill sands and gravels which form a more or less continuous cap in the northern and middle part of the Delmarva peninsula. This unit has provisionally been correlated with the Pensauken Formation of New Jersey. The marine units cap the southern part of the peninsula and include the Beaverdam Sand, a beach complex; the Walston Silt, a barrier–back barrier bar sequence; and the sand at Sinepuxent, an inner shelf deposit.

"Pots" in the Pliocene(?) gravels of northeastern Maryland

L. C. Conant has recognized irregular filled depressions or "pots" over a wide area in the high-level gravels in Cecil County, northeastern Maryland (loc. 11). The pots, filled with gray loam, are circular in cross section, some 6 to 8 feet deep, and about as wide. In plan they range from circular to strongly elliptical. The boundaries are sharp and in places are vertical or overhanging. The enclosing beds of old red sandy gravel are downfolded against the pots, and pebbles are alined parallel to the pot boundary as if they had been wedged aside.

The pots are invariably at ground level and are clearly related to the present-day land surface. The gravels which contain them are between 300 and 400 feet above sea level. The pots are suspected to be the results of some kind of ground-ice phenomenon and are presumably of Pleistocene age.

Ammonites from the Delaware coastal plain

The ammonites *Didymoceras stevensoni* and *Exiteloceras jenneyi* have been found along the Chesapeake and Delaware Canal near St. Georges, New Castle County, Del. (loc. 21), reports W. A. Cobban (r0594). *Didymoceras stevensoni* was enclosed in a matrix typical of the Marshalltown Formation of Late Cretaceous (Campanian) age and *Exiteloceras jenneyi* in a matrix typical of the Mount Laurel Sand, also Campanian in age. Both these species have previously been reported only from the western interior of the United States and provide another biostratigraphic link between that area and the eastern seaboard.

Structural features in the coastal plain of Georgia

A review of the numerous previous interpretations of the geologic structure in the coastal plain of southwestern Georgia (loc. 22) by S. H. Patterson and S. M. Herrick suggests that many supposed structural features in this area are without adequate supporting evidence. The subsurface evidence available now is insufficient to establish whether the Gulf trough, an elongate filled basin or embayment, represents a syncline, a graben, or only an aggraded strait. Reexamination of the geology related to the Ochlockonee fault failed to reveal evidence for its existence, and this formal name should be considered invalid.

Age and correlation of the Clinchfield Sand in Georgia

Recent studies by S. M. Herrick of the Foraminifera in the Clinchfield Sand at its type locality near Clinchfield, Houston County, Ga. (loc. 23), reveal the unit to be of early late Eocene (Jackson) age. The Clinchfield microfauna is the same as that in the Dellet Sand Member of the Moodys Branch Formation in Alabama and in a unit previously identified as the Cooper Marl near Baldock, S.C. Moreover, the Clinchfield is not the stratigraphic equivalent of the Gosport Sand of Alabama as previously thought.

STATES IN CENTRAL REGION AND GREAT PLAINS

CENTRAL REGION AND GREAT PLAINS

ARKANSAS

Geologic map of State

A revision of the State geological map, begun in 1968 as a cooperative project with the Arkansas Geological Commission, is about 60 percent completed. The map is being revised on the basis of published and unpublished reports and reconnaissance mapping. Two geologists of the U.S. Geological Survey and from two to four geologists of the Geological Commission are cooperating on the project. The revised map will be published at a scale of 1:500,000.

Age of Berger and Saline Formations and Detonti Sand, central Arkansas

R. H. Tschudy reports finding palynomorphs in the Berger Formation of central Arkansas (locality 1, index map) that are similar to those found in the Wilcox Group (lower Eocene and possibly upper Paleocene) of the southern Mississippi embayment. The Saline Formation and Detonti Sand, which overlie the Berger, contain palynomorphs similar to those of the Claiborne Group (middle Eocene) of the southern Mississippi embayment. Gordon, Tracey, and Ellis[56] considered that all three formations belong to the Wilcox Group.

KENTUCKY

Geologic mapping of State

A cooperative project with the State begun in 1960 was more than 65 percent completed by May 1, 1971, when 374 geologic maps had been printed (fig. 1) and another 58 maps approved for publication. Geologic mapping was in progress in more than 60 quadrangles. About 710 maps will be published to cover all 763 of the 7½-minute quadrangles that are wholly or partly within the State. The geologic maps are printed on recent editions of topographic base maps of the quadrangles, at 1:24,000 scale, and published in the Geologic Quadrangle Map series.

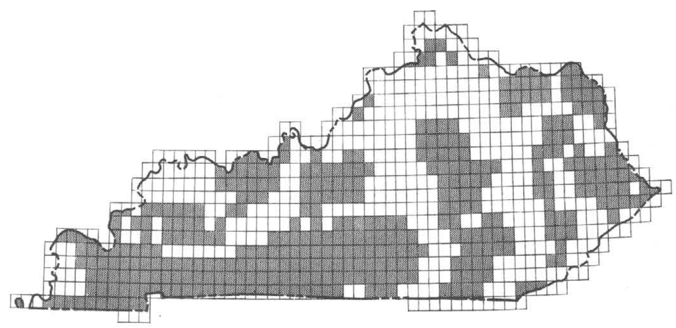


Figure 1.–Published geologic quadrangle maps (patterned) of Kentucky as of May 1, 1971; small squares are 7½-minute quadrangles.

Anvil Rock Sandstone Member of the Lisman Formation (Upper Pennsylvanian)

Mapping by T. M. Kehn in the Dekoven quadrangle (loc. 2), western Kentucky, reveals that the Anvil Rock Sandstone, considered a basal member of the Lisman Formation (Upper Pennsylvanian), is a channel deposit in the lower part of the Lisman Formation. From the type locality, which is within the

[56] Gordon, Mackenzie, Jr., Tracey, J. I., Jr., and Ellis, M. W., 1958, Geology of the Arkansas bauxite region: U.S. Geol. Survey Prof. Paper 299, p. 45, 53, 58.

Dekoven quadrangle, the member cannot be traced beyond the quadrangle boundaries; hence, identification of the unit in other areas by previous workers is placed in doubt.

Lower Devonian erosion surface and Upper Mississippian delta in central Kentucky

A Lower Devonian erosion surface in the Raywick quadrangle (loc. 3), Marion County, Ky., is reported by R. C. Kepferle to truncate strata that become progressively older eastward. Possibly as much as 110 feet of strata is missing in the eastern part of the quadrangle owing to this truncation. Correlation of lithologic and stratigraphic data from the Raywick and the adjoining Howardstown[57] quadrangles with data from a drill hole to the southeast suggests a lower Borden (Lower Mississippian) delta with a southwest-facing front that extends more than 25 mi southeasterly beyond the Raywick quadrangle. Two to three miles west of the delta front is a linear sandstone body as much as 120 feet thick that possibly represents an offshore bar.

Hydrothermal dolomitization of Upper Ordovician limestone in central Kentucky

D. F. B. Black found evidence in the Winchester quadrangle (loc. 4), Clark County, Ky., to indicate hydrothermal dolomitization in the Garrard Siltstone and Calloway Creek Limestone, both Late Ordovician in age. The dolomitized limestone is associated with faulting and is in an area traversed by barite dikes. Geologic conditions suggest the possibility that at depth mineralization may be associated with dolomitization.

Carter Caves Sandstone (Mississippian)—a new formation in northeastern Kentucky

A northeasterly-trending sandstone body of Mississippian age in northeastern Kentucky (loc. 5) is designated by K. J. Englund and J. F. Windolph, Jr., (p. D99–D104) as the Carter Caves Sandstone. The formation is about 30 mi long and is as much as 8 mi wide and 80 feet thick. It is composed dominantly of fine to medium quartz grains and contains minor amounts of quartz pebbles. The shape of the body and crossbedding indicates an offshore bar that was supplied with sediments derived from a northwesterly source, possibly from the area of the Cincinnati arch, which may have been a positive area during time of deposition of the Carter Caves Sandstone.

Middle Eocene—upper Eocene contact in the Jackson Purchase region, Kentucky

According to W. W. Olive, the contact between the Claiborne (middle Eocene) and Jackson (upper Eocene) Formations in the Wickliffe quadrangle, Ballard and Carlisle Counties, Ky. (loc. 15), is an erosional unconformity with as much as 75 feet of local relief. Throughout its extent in other parts of the Jackson Purchase region in Kentucky, this contact is poorly exposed or is concealed beneath younger surficial deposits. The relief along the unconformity and the lithology and sedimentary structures of the adjacent sediments suggest a regional uplift or climatic change at the close of Claiborne or beginning of Jackson time.

[57] Kepferle, R. C., 1966, Geologic map of the Howardstown quadrangle, central Kentucky: U.S. Geol. Survey Geol. Quad. Map GQ-505.

MICHIGAN

Source and deposition of Copper Harbor Conglomerate

The Copper Harbor Conglomerate (late Keweenawan) of Isle Royale (loc. 6) and the Keweenaw Peninsula on the north and south limbs, respectively, of the Lake Superior syncline was largely derived from volcanic terranes on opposite sides of the Lake Superior basin. The source rock of the formation on Isle Royale was the North Shore Volcanic Complex (middle Keweenawan) of Gehman[58] in Minnesota. As interpreted by N. K. Huber, the depositional environment was one that gave rise to fanglomerate and playa lake or flood plain deposits.

Sedimentary features indicate that the general transport direction on Isle Royale ranged from northeasterly to southeasterly but, in general, was easterly. The formation thickness and the textural and compositional maturity also increase in this direction. Thickness between two marker horizons increases from 1,500 feet to more than 6,000 feet in a distance of 20 mi–the total thickness of the formation cannot be determined because the top is nowhere exposed. Also, in an easterly direction, the composition of the formation grades from a boulder conglomerate into a conglomerate of cobbles and pebbles with interspersed sandstone, and then into sandstone.

Evidence of glacial history on Isle Royale

Progressively larger lakes occupied the Lake Superior basin in front of the upper Wisconsin ice sheet as it retreated northward near the close of the Wisconsin Glaciation. The highest unequivocal shorelines on Isle Royale (loc. 6) related to these glacial lakes are restricted to the western end of the island and occur at about 200 feet above the present level of Lake Superior. Geologic investigation on Isle Royale has revealed a complex of glacial deposits on the western end of the island that, as interpreted by N. K. Huber, were deposited marginal to the ice sheet during a brief pause in its retreat. The newly recognized ice-margin deposits extend across the island down to an elevation about 200 feet above present lake level and are east of the shorelines at that level. The deposits thus

[58] Gehman, H. M., Jr., 1958, The petrology of the Beaver Bay complex [Minn.] [abs.], *in* Institute on Lake Superior geology, April 21–22, 1958: Minneapolis, Univ. Minnesota Center Continuation Study, p. 1.

establish the local position of the ice margin during one stage in the postglacial evolution of Lake Superior, a stage that formed shorelines that are now approximately 200 feet above the present lake level. Because of postglacial uplift of Isle Royale, these shorelines do not indicate the absolute elevation of the lake at the time they were formed.

Stratigraphy and structure of the Porcupine Mountains

The upper northward-dipping limb of an overturned asymmetric anticline in western Michigan (loc. 7) is faulted near its axis. Geologic mapping by H. A. Hubbard indicates that near the southern margin of the Porcupine Mountains felsic to mafic lava flows of middle Keweenawan age are thrust over steeply dipping to overturned sedimentary rocks of late Keweenawan age. The sedimentary rocks are exposed to the south in an asymmetric syncline which has a steep north limb. Structural relief between the mountains and the syncline is more than 8,000 feet.

Depositional environment of Precambrian rocks in the East Gogebic Range

On the basis of evidence found in an 80-sq mi area of the East Gogebic Range (loc. 8), V. A. Trent suggests that Precambrian rocks in the area accumulated in a shallow-water marine environment, possibly one that was associated with an island arc. The rocks consist of lava flows, metasedimentary rocks, and igneous intrusives.

A shallow-water marine environment is suggested by pillow structure which is present at one place or another in all the Precambrian lava, and by ripple-marked bedding planes, algal structures, and scour fillings in the metasedimentary rocks. An island-arc setting is inferred by the similarity of the rock suite to that of present-day island arcs.

Trent suggests that the Wolf Mountain anticline, the most impressive structure in the area, is a large, asymmetrical, tightly folded structure that is standing on end. Tight folding of iron-formation and associated rocks in the anticline and tight crumpling observed in outcrops possibly occurred during late diagenesis.

Explanation of aeromagnetic anomalies in Ishpeming 7½-minute quadrangle

A 3-mi-long northwesterly trending aeromagnetic anomaly in the gneiss at Campau Creek (Precambrian) south of the Marquette synclinorium in the Ishpeming 7½-minute quadrangle (loc. 9) is due to a body of metadiabase, according to G. C. Simmons. This anomaly was previously thought possibly to be caused by iron-formation in the gneiss. Another anomaly of comparable size and trending easterly a short distance to the south is due to a lens of magnetite-bearing hornblende gneiss in the gneiss at Campau Creek.

Evidence of plate tectonics in Marquette County

Serpentinite, pillow lavas, and sparse metachert have been noted by L. D. Clark in the Negaunee SW quadrangle (loc. 10) in Marquette County. These rocks, which constitute the essentials of "Steinmann's Trinity", [59] are evidence to suggest ancient plate tectonics. Abundant intrusives are associated with and have the same composition as the lavas. The pillow lavas and associated intrusives are intruded into the Kitchi Schist (Precambrian).

Stratigraphic and structural relations of iron-ore bodies in Marquette County

The Humboldt open-pit iron mine, Marquette County (loc. 11), is developed in cherty specularite-magnetite. According to W. F. Cannon the ore zone is a stratigraphic unit as much as 200 feet thick at the top of the Negaunee Iron-Formation of Precambrian age. The mine is near the axis of an anticline which plunges 45° westward along the south limb of the Marquette synclinorium. The ore zone attenuates rapidly along strike toward the north limb of the anticline; southward, it is truncated by a steep fault that bounds subjacent Precambrian basement rocks. A series of north-trending, west-dipping reverse faults near the southern half of the ore body have telescoped the iron-formation, causing it to be repeated several times in vertical section. Two of the repeated parts of the ore body are within the Goodrich Quartzite (Precambrian), which is stratigraphically above the Negaunee. The upper section is the Foxdale ore body which previously was exploited by underground methods. Other repeated sections of the ore body may occur beneath cover west of the Humboldt pit. Reconnaissance by ground magnetometer, however, indicates that about 1 mi west of the Humboldt mine the iron-formation is absent, and the Goodrich Quartzite probably rests directly on basement rocks.

MINNESOTA

Wisconsin Till in the Iron Range area

Glacial till of Wisconsin age, representing three ice lobes in the Iron Range area (loc. 12) of northeastern Minnesota is recognized by T. C. Winter, R. D. Cotter, and H. L. Young (p. C82–C88).[60] Ages of the tills have been determined on the basis of radiocarbon dating by previous workers. The earliest lobe moved eastward into the area south of the Giants Range and withdrew more than 35,000 yr ago. It deposited a dark-greenish or brownish-gray, sandy, silty, calcareous till that is well exposed only in a few open-pit iron mines. The second

[59] Hess, H. H., 1955, Serpentines, orogeny, and epeirogeny: Geol. Soc. America, Spec. Paper 62, p. 391–407.

[60] Winter, T. C., Cotter, R. D., and Young, H. L., 1971, Petrography and stratigraphy of glacial drift, Mesabi-Vermilion Iron Range area, northeastern Minnesota: U.S. Geol. Survey Bull. 1331-C. [In press]

ice advance, the Rainy lobe, invaded from the northeast and receded 14,000 to 16,000 yr ago. It deposited bouldery till that has a yellow to red, sandy, silty matrix. The last advance, the St. Louis sublobe of the Des Moines lobe, entered the area from the northwest more than 10,000 yr ago. In the western part of the Iron Range area and north of the Giants Range it deposited gray, silty, calcareous till; it deposited red clayey till south of the Giants Range. The clay of the till was probably derived from lacustrine deposits that in turn were derived from red drift of an earlier Wisconsin ice lobe that did not extend into the Iron Range area.

WISCONSIN

Precambrian rocks in Ashland, Iron, and Vilas Counties

Reconnaissance investigations by C. E. Dutton in an area that embraces parts of Ashland, Iron, and Vilas Counties (loc. 13) indicate that outcrops of Precambrian rocks are small and scattered and consist of varieties of micaceous schist, except locally where the rocks are fine- to medium-grained and mafic and, for the most part, are probably metabasalt. As revealed by study of drill cores from several explorations, grunerite, garnet, and quartz are commonly and, at places, abundantly associated with magnetite of the iron-formation or iron-formations.

Rocks adjacent to iron-formation consist of micaceous schist, graywacke, and metabasalt(?), but stratigraphic and age relations of bodies of iron-formation and of the associated rocks have not been determined.

A metasedimentary unit in the southernmost part of the area is a kyanite-garnet-biotite schist that locally contains staurolite crystals as much as 1 inch long. The schist is cut by granite that is probably related to a mass which, as indicated by scattered outcrops of granite further south, is probably large.

Precambrian and Upper Cambrian rocks in Jackson County

Harry Klemic reports that numerous dolerite dikes of two ages and granitic dikes and masses intrude Precambrian metasedimentary gneisses and iron-formation in Jackson County (loc. 14). Dikes and large granitic masses are jointed but are unfoliated and exhibit little evidence of deformation. Atypical columnar jointing in one small dolerite dike may reflect cooling at a relatively shallow depth. The Precambrian rocks are overlain unconformably by sedimentary rocks of Late Cambrian age. The contact is an erosional surface with a very gentle southward slope; however, locally isolated buried hills rise as much as 100 feet above the general level of the ancient surface. A thin conglomeratic zone at the base of the Late Cambrian sequence consists mainly of pebbles and fragments of quartz in a quartz-sand matrix except in areas of the ancient hills where the fragments are largely of quartzite and iron-formation derived from the underlying Precambrian rocks. Pebbles of the conglomeratic zone at many places resemble ventifacts, but some are fragments of thin flat-sided veins, and their form may be due in part to weathering agents other than aeolian. Grab samples of friable sandstone representing a thickness of nearly 400 feet of the Upper Cambrian stratigraphic section near Black River Falls contain 80 percent of medium to fine sand and about 12 percent of finer grained material.

NORTHERN ROCKY MOUNTAINS

MINERAL-RESOURCE STUDIES

Copper in Precambrian rocks of Montana

M. R. Mudge (r1003) and R. L. Earhart report that weak copper mineralization is widespread in green to greenish-gray clastic Precambrian rocks in the Lincoln Back Country area, Montana (locality 1, index map); the copper-bearing strata

commonly are 1 inch or less to about 1 foot thick, rarely as much as 3 feet thick, and from a few inches to nearly 200 feet long. Representative channel samples contain a maximum of 0.2 percent Cu over a thickness of 3.2 feet. The copper minerals are, in order of abundance, malachite, bornite, azurite, chalcopyrite, and chalcocite, occurring mostly along fractures, along bedding planes, and in the intergranular voids of porous rocks. The copper is probably of late diagenetic origin and was leached from oxidized red beds and redeposited in reduced green beds during the accumulation of the sedimentary rocks.

A different conclusion on the origin of such copper deposits has been reached by J. E. Harrison, who considers that stratabound copper ores in the Revett Formation owe their concentration to post-Revett epigenetic processes. This conclusion differs significantly from most current hypotheses which consider the stratabound ore as syngenetic or early diagenetic and in place. A synthesis of geometry and tectonics identifiable by facies changes and isopachous maps has been prepared by Harrison, utilizing in particular critical data not yet published by F. K. Miller, A. B. Griggs, and J. D. Wells. The copper ores consist of bedding-plane disseminations, blebs, and irregular patches of mostly bornite-chalcocite-chalcopyrite-covellite, according to A. L. Clark (r2514), who also notes that some ore is in veinlets filling fractures. Regionally the ores are in quartzite layers in the Revett in a north-trending zone about 40 mi wide and 120 mi long in western Montana adjacent to the Idaho panhandle. The Revett is in the Ravalli Group, which is overlain by the Wallace Formation, which is in turn overlain by the Missoula Group—the uppermost group in the Belt Supergroup. Isopachous maps show that the copper sulfide ore zone is perpendicular to the Revett trough but parallel to a low dome formed in early Missoula time, indicating post-Revett epigenetic reconcentration of copper.

Platinum at Cooke City, Mont.

Continuing studies by J. E. Elliott of the Copper King prospect, a chalcopyrite deposit in syenite near Cooke City, Mont. (loc. 2), indicate widespread potassium metasomatism associated with mineralization; potassium feldspar is intimately intergrown with chalcopyrite, and plagioclase was replaced by potassium feldspar. Veinlets of potassium feldspar are evident in stained slabs of mineralized syenite. Assays of ore from the Copper King dump confirm earlier reports of appreciable platinum-group metal content. Assays of three samples indicated: 0.5 to 10 ppm Pt, 0.15 to 3 ppm Pd, and as much as 0.04 ppm Rh.

Geologic studies in the Hecla district, Montana

South of the Hecla mining area near Melrose, Mont. (loc. 3), E-an Zen has found that intrusive igneous rocks are predominantly coarse gray porphyritic quartz monzonite similar to the Butte Quartz Monzonite, but that large areas are underlain by several varieties of quartz diorite and diorite, some granite, and at least one small body of coarse pyroxenite. The gold, silver, lead, zinc, and copper mineralization in the Hecla area and tungsten mineralization near Brown's Lake are concentrated in carbonate rocks near the intrusive contact. Metamorphic effects are more widespread; the rocks as much as 3 mi from visible igneous contacts have been altered to marble, hornfels, and schist. Zen finds, too, that the Precambrian and lower Paleozoic sedimentary sequence in this area differs considerably from the standard section for western Montana. The facies change is rapid, as just east of Melrose the Camp Creek section is nearly identical with the Three Forks section. The Precambrian rocks are in several sandstone—conglomerate sequences, several hundred to thousands of feet thick. The contact between the Paleozoic rocks and Precambrian rocks is problematic as there seems to be intercalation of typical Meagher limestones and conglomerates more typical of the Precambrian sequences. A black silty shale that intervenes between them locally could be the Wolsey equivalent. The contact is at most a disconformity where observed. The Cambrian rocks above the contact zone are a thick sequence of massive dolostone.

Natural-gas potential in the Bearpaw Mountains, Mont.

In the Bearpaw Mountains, Mont. (loc. 4), electric log data indicate that much of the downfaulting and tilting of Tertiary sedimentary rocks and volcanic rocks is due to collapse in the extension zone of one or more gravity-slide sheets. This structural interpretation by B. C. Hearn, Jr., suggests that additional reservoirs of natural gas in the Eagle Sandstone and Judith River Formation (Cretaceous) may be found by testing the structure beneath (1) anticlines and domes of volcanic rocks, (2) inliers and embayments of Tertiary sedimentary rocks, (3) updip edges of tilted fault blocks of volcanic rocks, (4) downfaulted blocks of Tertiary sedimentary rocks, and (5) areas of Cretaceous rocks between downfaulted blocks.

Calderas and ore deposits in Idaho

Some of the principal faults of the Big Creek—Yellow Pine area, central Idaho (loc. 5), are ring fractures and radial fractures related to the Tertiary Thunder Mountain caldera studied by B. F. Leonard. The largest silicified zones of the area—long known to contain minable deposits of antimony, gold, silver, tungsten, mercury, and minor base metals—occupy two parallel belts of ring fractures in granitic and metamorphic rocks on the west side of the caldera. The outer belt defines the west border of the Thunder Mountain cauldron and contains the Profile—Smith Creek swarm of Tertiary dikes. Remnants of Precambrian syenite found along the cauldron edge may represent an ancient plutonic ring complex whose gross outline perhaps determined the site of the relatively young cauldron from which the Challis Volcanics of the Thunder Mountain caldera exploded in early(?) to middle Tertiary time. The Thunder Mountain caldera is interpreted as the simplest and best preserved member of a chain of calderas that extends 160 mi southeastward to the Snake River Plain, cutting diagonally across the Idaho batholith and its Precambrian and Paleozoic roof rocks. The intricate arrangement of gravity-slid(?) blocks of Paleozoic rock about some of these putative calderas may owe its beginnings to distention of the cover rocks as magma swelled within the Tertiary cauldrons before the explosive, local eruption of the Challis Volcanics. Some of the vein and replacement ore deposits of south-central Idaho are spatially related to these complex calderas.

Uranium potential in Wyoming

Near the Crooks Gap uranium district, south-central Wyoming (loc. 6), L. J. Schmitt, Jr., has divided the Battle Spring

Formation, of Eocene age, into five units that alternately are relatively oxidized first-cycle sediments and relatively reduced first-cycle sediments with a significant second-cycle component. At least two of the reduced units are thought to be favorable for localization of uranium deposits.

Mercury in the Phosphoria Formation

Mercury analyses were made of 102 samples of black shale and phosphorite in the Phosphoria Formation (Permian) in the Jackson and Afton areas, 50 mi apart, in northwestern Wyoming (loc. 7). Values range from 150 to 1,200 ppb Hg in a zone that also is highest in vanadium, silver, selenium, chromium, and several other trace elements; the zone is 4 to 10 feet thick. Mercury has not been described before from the Phosphoria Formation of northwestern Wyoming, but J. D. Love suggests that it might locally be of economic and environmental interest. Because of its occurrence in phosphate rock, effluents from phosphate plants and refined phosphate from the Phosphoria should be checked for mercury, as should oil and sulfur from this formation and its stratigraphic equivalents in central and northern Wyoming.

MONTANA DISTURBED BELT

The Montana lineament and the disturbed belt

R. G. Schmidt, G. D. Robinson, M. E. McCallum, W. H. Hays, and W. B. Myers have shown that the Montana disturbed belt, a broad north-trending zone of intense Laramide folding and thrust faulting in western Montana, passes undeflected across the trend of the Montana lineament; the lineament exists and has evidently played a significant role in the tectonic history of the northern Rocky Mountains, but that role has apparently not included demonstrable left-lateral movement at any time or large post-Cretaceous movement of any kind.

Dating the Eldorado thrust

H. H. Mehnert and R. G. Schmidt have obtained a K-Ar date of 58.3 m.y. on biotite in a quartz monzonite porphyry sill intruded into, and therefore younger than, the Eldorado thrust zone along the eastern front of the Lewis and Clark Range in the disturbed belt near Wolf Creek, Mont. (loc. 8). The age of 58.3 m.y. therefore provides a fairly precise upper limit on the time of movement on the Eldorado thrust at this locality. The date may also represent an upper limit on the time of regional deformation in this part of the Montana disturbed belt, for along its trace to the north and south the Eldorado thrust truncates structures in underlying rocks of the St. Mary River and Two Medicine Formations of Late Cretaceous age and the Willow Creek Formation of Late Cretaceous and Paleocene age, and the thrust is believed to have formed at a late stage in the orogenic history of the region.

YELLOWSTONE AND GRAND TETON NATIONAL PARKS
(loc. 15 and 16)

Collapse calderas and the Rhyolite Plateau

R. L. Christiansen and H. R. Blank, Jr., have shown that volcanic activity of the Yellowstone Rhyolite Plateau region includes three cycles, each climaxed by the eruption of a large-volume rhyolitic ash-flow sheet and formation of a large collapse caldera. Smaller volumes of rhyolitic lavas were erupted within the source areas of each of the major ash-flow sheets, and relatively minor amounts of rhyolite and basalt were erupted through flanking vents. Climactic eruptions of the youngest cycle occurred about 600,000 yr ago from two partly intersecting ring-fracture zones in the central part of Yellowstone National Park, and the related collapse formed an enormous composite caldera, about 30 by 50 mi across, with two resurgent domes. The major ash flows of the middle volcanic cycle were erupted about 1.2 m.y. ago and formed a caldera about 10 mi in diameter in the Island Park area of Idaho, just west of Yellowstone National Park. Major eruptions of the oldest of the three volcanic cycles, about 2 m.y. ago, resulted in collapse on three intersecting ring-fracture zones to form a caldera at least 50 mi long that probably spanned parts of both the Yellowstone and Island Park areas.

Grand Canyon of the Yellowstone

The history of the Grand Canyon of the Yellowstone is different in its northern and southern parts. In its northern part, geologic studies by R. L. Christiansen and K. L. Pierce and preliminary K-Ar dates measured by J. D. Obradovich have shown that a valley cut in a 2-m.y.-old welded tuff was partly filled with till and gravel containing a pumice unit 1.6 m.y. old. These strata were buried by a welded tuff 0.6 m.y. old. Subsequently, the canyon was cut again, filled with basalt flows and gravel, eroded again, filled with glacial deposits, and finally eroded to its present depth.

The southern part was first cut in a rhyolite flow intruded along the inner margin of a caldera produced by eruption of the 0.6-m.y.-old welded tuff. Investigations by G. M. Richmond, H. A. Waldrop, R. L. Christiansen, and J. D. Obradovich show that this canyon was partly filled with middle Pleistocene till and lake deposits containing several pumice units, the oldest about 0.3 m.y. old. The head of the canyon was then overlapped by a rhyolite flow about 112,000 yr old. Subsequently, the canyon has been reexcavated to its present depth and overridden by glaciers at least twice in late Pleistocene time.

Geochronologic studies in the Teton Range

Rb-Sr and K-Ar isotope studies by J. C. Reed, Jr., have established a tentative chronology for the major Precambrian rock units in the Teton Range, Wyo. Whole-rock Rb-Sr determinations on syntectonic granite gneiss fit an isochron at 2.81±0.14 b.y. with an initial Sr^{87}/Sr^{86} value of 0.70059. This finding probably dates an event during which the layered gneisses of the range were metamorphosed and folded.

Whole-rock determinations on discordant posttectonic granites and pegmatites fit an isochron at 2.50±0.13 b.y. with an initial ratio of 0.73221. The high initial ratio suggests that this may be a minimum age rather than a true age. An attempt is being made to recover enough zircon for a U-Pb determination as a check. Separated minerals (plagioclase, microcline, biotite, and muscovite) from a granite sample which lies on the whole-rock isochron show considerable scatter. The feldspars fit an isochron at 1.8 b.y., but biotite gives an age of 2.3 b.y. and muscovite an age of 1.5 b.y. This scatter indicates that considerable redistribution of strontium has occurred among coexisting minerals and suggests that carbon should be used in interpreting the whole-rock age.

In an attempt to date the emplacement of unmetamorphosed Precambrian diabase dikes, K-Ar ages have been determined on biotite and hornblende in the wallrocks along a transect normal to the walls of the 150-foot-thick dike on Mount Moran. The wallrock biotites show ages of 1.3 to 1.4 b.y. even at distances of only 5 feet from the contact. The absence of any lowering of ages adjacent to the dike suggests that the dike was emplaced prior to the thermal event that reset biotite K-Ar clocks.

Hornblende in the wallrocks has K-Ar ages of about 2.8 b.y. at distances of 10 feet and more from the dike. The apparent age decreases to 2.6 b.y. 2 feet from the dike. This difference suggests that the event which reset the biotite ages did not affect the hornblende and that a lowering of hornblende ages may be detectable. Other samples of hornblende closer to the dike are now being analyzed.

A single whole-rock K-Ar determination on fine-grained diabase at the dike margin gives an apparent age of 775 m.y. This result is inconsistent with the biotite data and suggests that the whole-rock date is fictitious.

Uplift along and near the Teton fault

The amount of late Cenozoic uplift of the Tetons and subsidence of Jackson Hole, Wyo. is pertinent to many problems of environmental planning and interpretation in and near Grand Teton National Park. New data, which permit structure contouring of the mountain and basin blocks on the base of the tuff of the Yellowstone Group (Pleistocene), suggest that during the past 2 m.y. the eastern edge of the Teton mountain block was probably uplifted 2,000 to 4,000 feet and tilted westward, and that the maximum amount of displacement was along the Teton fault at the east base of the range. Similarly, the Jackson Hole block was downtilted about the same amount near the Teton fault, with the hinge line of westward tilting somewhere east of Grand Teton National Park. The average rate of movement in the area of greatest displacement along the Teton fault was probably 1 foot in 500 to 1,000 yr.

GEOLOGICAL AND GEOPHYSICAL STUDIES

Snake River Plain

Three-dimensional models have been developed by E. S. Robinson to explain the aeromagnetic and gravity anomalies in the area of the National Reactor Testing Station, Idaho (loc. 9). The magnetic anomalies appear to come from a surface layer of volcanic rock generally less than 1 km thick, and the gravity anomalies are explained by density contrasts extending to 3 km below the surface. This part of the Snake River Plain appears to be an area formerly characterized by Basin and Range physiography that has subsided and been covered by Cenozoic volcanic and sedimentary rocks.

Three north-south profiles of deep Schlumberger and equatorial soundings were made between Minidoka and American Falls, Idaho, by A. A. R. Zohdy (r1230) to map differences in the thickness of the Snake River basalt, the main ground-water aquifer in the area. Three wells drilled to a depth of about 1,000 feet each confirmed the results obtained from the interpretation of the electrical soundings. The high-resistivity (500–2,000 ohm-m) basalt is from 0 to 3,000 feet thick and is underlain by as much as 8,000 feet of low-resistivity (20–35 ohm-m) sedimentary rock.

Thrust faulting in central Idaho

Geologic mapping by S. W. Hobbs and W. H. Hays in the Lone Pine Peak quadrangle (loc. 10), Custer County, Idaho, has documented significant differences in the detailed lithology of the Ella Dolomite (Middle Ordovician) as exposed east of Germer Peak from that exposed at Alkali Springs a few miles to the south. Likewise, the character of the underlying Clayton Mine Quartzite is very different at the two places. Ella Dolomite at Alkali Springs, however, is identical in most details with the type section near Clayton. The Germer Peak Ella Dolomite section and the Alkali Springs Ella Dolomite section, although nearly on strike, are separated by a westward-dipping low-angle thrust fault that roughly follows the northward-trending valley of the Salmon River. The notable differences in stratigraphy between the two nearly juxtaposed segments of the same formation strongly suggest major movement on the fault that separates them.

Westernmost inlier of Devonian and Silurian rocks in central Idaho

C. A. Sandberg and B. A. Skipp have identified Devonian and Silurian miogeosynclinal formations in a window beneath a thrust sheet of younger Paleozoic rocks in the Pioneer Mountains, Idaho (loc. 11), about 35 mi west of previously known outcrops of the same formations. The Laketown Dolomite (Silurian) and the lower part of the Jefferson Formation (Devonian) resemble these formations to the east. The upper part of the Jefferson, however, is conglomeratic quartzite containing carbonate pebbles and resembles conglomeratic parts of the Beirdneau, Stansbury, and Victoria Formations in Utah; these rocks suggest the northward extension, across the Snake River Plain, of Late Devonian uplift within the miogeosyncline.

Precambrian sedimentary rocks in east-central Idaho

The Precambrian sedimentary rocks in the central part of the Lemhi Range (loc. 12), east-central Idaho, have been separated by E. T. Ruppel into six mappable units, mostly feldspathic quartzite, having an aggregate thickness of about 35,000 feet. In the northern part of the Lemhi Range and in much of the adjacent Beaverhead Range, these rocks appear to be underlain by a succession of micaceous, feldspathic quartzites of unknown but probable great thickness; in the southern part of the Lemhi Range they are overlain by about 1,700 feet of dolomitic, glauconitic sandstone, gray shale, and conglomerate. The six units in the central part of the Lemhi Range and the underlying micaceous quartzite probably are equivalent to some part of the Belt Supergroup of western Montana and northern Idaho, perhaps largely to rocks of the Ravalli Group and below. The overlying rocks at the south end of the Lemhi Range probably are partly post-Belt Precambrian and partly Cambrian in age, equivalent to rocks of similar age in southeastern Idaho and in Utah.

Possible Absaroka Volcanic Supergroup equivalents near Pocatello, Idaho

Hornblende andesite laharic breccia on the west side of the Blackfoot River valley in the Fort Hall Indian Reservation (loc. 13) has been found by D. E. Trimble to be separated from overlying Starlight Formation (Pliocene) by a major unconformity. Total relief on the surface of the unconformity probably is hundreds of feet, and the breccia beneath the unconformity is severely weathered to a depth of about 100 feet. The time required for this depth of weathering suggests that these rocks probably are lower Tertiary and perhaps Absaroka equivalents.

Faulting near Henrys Lake, Mont.

Structural complexes in the Henrys Lake quadrangle (loc. 14) include the Madison Range and Madison Valley, tilted fault blocks that trend northwest, and the Centennial Range and Centennial Valley, also tilted fault blocks, that trend east; these complexes meet in the Henrys Lake basin, according to I. J. Witkind. Gravity surveys indicate that the Centennial Range normal fault ends near the west edge of the basin and does not extend across the south end of the Madison Range–Madison Valley complex. Linear scarps in the surficial deposits that floor the basin are relicts of ice-marginal channels possibly formed during Bull Lake Glaciation and so are unrelated to the structural elements.

Geochronologic problems in the Belt Supergroup

In their development of a chronology of the Belt Supergroup through application of Rb-Sr dating methods to clay rocks, J. D. Obradovich and Z. E. Peterman[61] earlier found that the Neihart, Chamberlain, Newland, and Greyson Formations yielded a single Rb-Sr age of 1,325±15 m.y., and that a higher sequence of units, the Helena, Snowslip, Shepard, Mount Shields, Bonner, and McNamara Formations, yielded a single Rb-Sr age of 1,100±53 m.y. In an attempt to date the gap between the Greyson and Helena Formations–occupied by the Spokane and Empire Formations–Obradovich and G. D. Robinson collected a suite of 11 samples from the Empire Formation east of Helena, Mont. The tentative isochron yielded by this suite is a startingly young 600 m.y., suggesting that: (1) the sampled rocks are Empire Formation and have been affected by a heretofore unrecognized Early Cambrian thermal event; or (2) the rocks are not Empire Formation, despite their appearance and their seeming gradation downward into type Spokane Formation, but are a heretofore unrecognized unit of Early Cambrian age; or (3) the Rb-Sr whole-rock method has heretofore unrecognized complexities.

SOUTHERN ROCKY MOUNTAINS

MINERAL-RESOURCE STUDIES

Dolomitization in the Colorado mineral belt

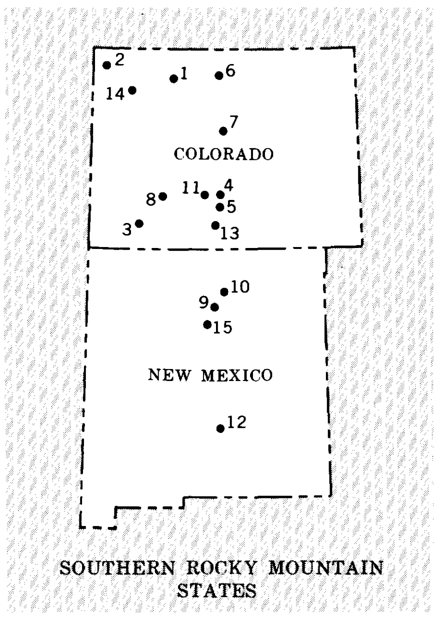
A geologic model accounting for the widespread occurrence of dolomite in the central Colorado segment of the Colorado mineral belt has been devised by Ogden Tweto and T. S. Lovering. The Leadville Limestone is dolomitized throughout this part of the mineral belt, and in several areas, including, but not limited to, the mining districts, the dolomite is recrystallized. Dolomitization began in earliest Laramide (Late Cretaceous) time under the influence of (1) moderate heating above a batholith that was beginning to rise beneath the mineral belt, and (2) the first rise of the huge Sawatch Range anticline. Tilting of the rocks in the anticline caused ground waters to start to circulate, carrying magnesium from evaporite-rich Pennsylvanian rocks into the underlying Leadville

[61] Obradovich, J. D., and Peterman, Z. E., 1968, Geochronology of the Belt Series, Montana: Canadian Jour. Earth Sci., v. 5, p. 737–747.

Limestone on the flank of the anticline. Under conditions of slightly elevated temperature, these waters dolomitized the limestone, in accord with principles discussed by Lovering.[62] With passing time, some areas, presumably above swells in the batholith, were heated further, and in these areas the dolomite recrystallized. Later, ore solutions rose from some of the batholithic swells or cupolas that had caused the dolomite to recrystallize and formed ore deposits in parts of some of the recrystallized areas, as in the Gilman, Leadville, and Alma mining districts.

Platinum-group elements in dunite

Traces of platinum and palladium have been detected by G. L. Snyder in a small dunite body east of Clark, Colo. (locality 1, index map). The dunite originally consisted of three-quarters or more of olivine (chrysolite Mg_{75}), more than



80 percent of which is now altered to serpentine, chlorite, and magnetite. Other minerals in order of importance are pargasite (?Mg_{93}?), bronzite (Mg_{82}), ceylanite(?), magnetite, diopside (Mg_{90}), chromite, and bytownite, all of which occur both intermixed as individual crystals among the olivine crystals and also as parts of discrete layers within coronas, the centers of which are a myrmekite of the spinel and the amphibole.

Nahcolite in northwest Colorado

Three core holes drilled in the saline facies of the Green River Formation (Eocene) in the Piceance Creek basin (loc. 2), northwest Colorado, were analyzed quantitatively for nahcolite ($NaHCO_3$), a potential source of soda ash. Nahcolite-bearing rocks begin in the core holes at depths of 1,400 to 1,850 feet and range from 556 to 702 feet in thickness. Two wells did not completely penetrate these rocks however. The average nahcolite content for the sequence of rocks analyzed in each core hole ranges from 18 to 26 wt percent, and tonnages calculated range from 187 to 292 million short tons per sq mi according to J. R. Dyni.

San Juan Mountains, Colo.

The variety and distribution of clay minerals suggests a zoning pattern in some of the chimney ore deposits in the Red Mountain mining district (loc. 3), San Juan Mountains, Colo. according to R. G. Luedke and J. W. Hosterman (p. C104–C111). From the center of the ore body, characterized by acid-sulfate alteration, outward to the propylitically altered country rock, the zones are: (1) high-alumina montmorillonite, (2) high-alumina montmorillonite and pyrophyllite, (3) high-alumina montmorillonite, pyrophyllite, and dickite, (4) dickite and illite, and (5) illite and chlorite.

F. S. Fisher (USGS) and J. N. Mayor (Idarado Mining Co.) report that upper Tertiary replacement ore deposits of significant size and number are present in the Telluride Conglomerate (Eocene) adjacent to northwest-trending veins on the northwest side of the Silverton caldera in the San Juan Mountains. Sphalerite, galena, chalcopyrite, and pyrite are the major sulfide minerals, and the ores carry some cadmium, bismuth, silver, and minor gold. Major gangue minerals are quartz, epidote, chlorite, rhodonite, and carbonates, along with lesser amounts of sericite, and clay minerals.

Overall changes in the Telluride Conglomerate due to alteration are quite pronounced, with the normally reddish units becoming gray to green owing to development of chlorite and sericite in the matrix. Near the ores the grays and greens give way to pinks and pale green as a result of the development of manganese-bearing epidote, carbonates, and rhodonite.

The Telluride Conglomerate appears to be the most favorable host rock in the district, although some potential is also present in the Cutler and Dolores Formations. Permeable, calcareous, conglomeratic rock units adjacent to base-metal veins were the most favorable rocks for replacement.

Vermiculite in the Wet Mountains

Vermiculite deposits studied by Q. D. Singewald near Westcliffe, Colo. (loc. 4), are in a Precambrian unit of amphibolite and hornblende gneiss. The vermiculite developed, probably by weathering, only in thin, very sparse lenses of biotite schist within the amphibolite. At one locality a biotite schist lens contains large garnets whose X-ray diffraction pattern shows a major content of pyrope. The vermiculite

[62] Lovering, T. S., 1969, The origin of hydrothermal and low-temperature dolomite: Econ. Geology, v. 64, no. 7, p. 743–754.

bears no relationship to the proximity of Lower Cambrian dikes.

PRECAMBRIAN ROCKS IN COLORADO

Pikes Peak batholith

The constituent subalkaline biotite granite, biotite-fayalite granite, and quartz syenite of the Precambrian Pikes Peak batholith (loc. 5) of the Colorado Front Range, as shown by 29 new chemical analyses reported by Fred Barker, are characterized by MgO contents of less than 0.4 wt percent (at 63 percent of SiO_2) to less than 0.1 percent (at 76 percent SiO_2), high FeO/MgO values—FeO contents are similar to those of calc-alkaline rocks—and relatively low values of Fe_2O_3/FeO. This batholith, therefore, is compositionally similar to the Gardar syenites of Greenland, to the ring-dike complexes of New Hampshire and Nigeria, and to the slightly more calcic Rapakivi granites of Finland and the U.S.S.R. These rocks probably formed from magmas that were generated by zone melting in the lower to middle crust. In this process a basic alkaline "starter" magma from the mantle presumably moved upward by melting its crustal roof and by simultaneously precipitating olivine, clinopyroxene, and plagioclase onto the floor of its chamber. After extensive change in composition of the magma to that of a granite with more than 72 percent SiO_2, the roof failed and the batholith moved upward in piecemeal and discordant fashion.

Northeast Front Range

Large east- to northeast-trending shear zones that cut Precambrian rocks in the Poudre Park and Big Narrows quadrangles, Colorado (loc. 6), contain well-developed layered mylonites, according to W. A. Braddock and J. T. Abbott. Andalusite-cordierite mineral assemblages in the immediately adjacent metasedimentary rocks suggest that the conditions under which the hornblende-hornfels metamorphic facies was formed occurred during mylonitization. Rb-Sr whole-rock analyses indicate that mylonitization probably occurred about 1.2 b.y. ago.

Gneiss domes at Indian Hills

In the Indian Hills quadrangle, Colorado (loc. 7), mapping of the Precambrian rocks by Bruce Bryant shows that east of the Floyd Hill fault system the structure consists of two gneiss domes separated by a gently east-plunging syncline. West of the fault zone the early major folds trend north-south and plunge gently. The mesoscopic structures formed during a younger deformation; girdles formed by foliation plots indicate that the structures plunge steeply parallel with mineral lineations and axes of minor folds. Faulting along the northwest-trending Floyd Hill fault zone has had a long history from early movements during the metamorphism about 1,700 m.y. ago to the time of Laramide deformation. Precambrian movements were apparently left lateral; later movements were vertical with the northeast side moving upward.

Felsic metavolcanic rocks near Gunnison, Colo.

A unit of predominantly felsic metavolcanic rocks of Precambrian age, inferred to be at least 1 mi thick, has been mapped by J. C. Olson in an area about 3 mi wide near Green Mountain in the Iris quadrangle, Gunnison and Saguache Counties, Colo. (loc. 8). The felsite is in large part of pyroclastic origin, including ash-flow tuffs, but may include smaller amounts of intrusive rocks or lava flows. It is generally a porphyritic rhyodacite to dacite or quartz latite containing phenocrysts of quartz and oligoclase. Similar widths and thicknesses have been found by Olson and D. C. Hedlund westward and southwestward in the Iris NW, Powderhorn, and Gateview quadrangles. The felsite is part of a major Precambrian volcanic sequence that includes the intermediate to mafic flows and pyroclastics of the Dubois Greenstone, intrusive metadiorites, and interbedded metasedimentary rocks such as chert, siltstone, and aluminous sedimentary rocks that locally contain staurolite, kyanite, and garnet. The large component of felsic volcanics in this sequence has only recently been brought to light.

SAN JUAN MOUNTAINS, COLO.
(loc. 3)

Volcanic chronology throughout the San Juan volcanic field

T. A. Steven, P. W. Lipman, and R. G. Luedke report significant modifications in volcanic stratigraphy and structural interpretations in the San Juan Mountains. The Gilpin Peak Tuff of the Silverton, Colo., area is equivalent to four major ash-flow sheets mapped and named by J. C. Olson, D. C. Hedlund, and W. R. Hansen, and by R. G. Dickinson in the vicinity of the Gunnison River (in ascending order: tuff of Storm King Mountain, Blue Mesa Tuff, Dillion Mesa Tuff, and Sapinero Mesa Tuff). The principal subsidence of the Silverton caldera appears to have been related to eruption of the Sapinero Mesa Tuff, which has been traced eastward for nearly 75 mi along the north flank of the volcanic field to the vicinity of Saguache, Colo. Two buried calderas in the headwater area of the Rio Grande are probable sources for older sheets of this ash-flow sequence. Volcanic chronology between the eastern and western parts of the field is now reasonably firm for the first time in more than 80 yr of nearly continuous geologic work in the San Juan Mountains.

Mix lavas in the San Juan volcanic field

Mapping near the north rim of Platoro caldera has led to recognition of two heterogeneous lava flows, interpreted by P. W. Lipman as mixes of mafic and silicic components. Both display textural and structural features similar to those of the Gardiner River Rhyolite-Basalt Complex in Yellowstone National Park, described by R. E. Wilcox in 1944. One unit, an intrusive-extrusive complex in which coarsely porphyritic silicic quartz latite is interlayered with nonporphyritic andesite, demonstrates that these contrasting magma types were erupted simultaneously from the same vent system. The other unit is a mix of olivine basalt and silicic rhyolite containing quartz phenocrysts. Parts of this unit consist of relatively homogenous-appearing basaltic andesite, containing quartz xenocrysts, that is similar to numerous other xenocrystic basalts and basaltic andesites of Miocene-Pliocene age (Hinsdale Formation). Probably many of these other rocks also are relatively homogenized mixes of basaltic and rhyolitic magma.

Geophysical investigations in the San Juan Mountains

A two-dimensional interpretation by Donald Plouff of a gravity low and a correlated magnetic high indicate the approximate configuration of a postulated batholith beneath the San Juan Mountains, Colo. The depth to the top of the batholith ranges from less than 2 km to 7 km beneath the surface along the interpreted profile. The bottom of the batholith may extend to a depth greater than 19 km. A number of local gravity highs in the San Juan Mountains area are correlated with Tertiary intrusive and Precambrian rocks.

STRUCTURAL AND GEOPHYSICAL STUDIES

Folding in the Sangre de Cristo Mountains

The southern Rocky Mountains, as represented in New Mexico by the Sangre de Cristo Mountains (loc. 9), terminate to the south on an extremely broad anticlinal fold that regionally dips away from the central core of the mountains at angles averaging only 2° to 3°. It was found earlier that the southeastern flank of this broad fold was distorted by a sinuous monoclinal flexure associated with several normal faults. Recent mapping by R. B. Johnson in the Bull Canyon quadrangle indicates that the southwestern flank of this large regional fold is also distorted by a sinuous monoclinal flexure associated with several normal faults. The southwestern flank appears to be nearly a mirror image of the southeastern flank.

Gravity studies in the Rio Grande graben

A large gravity low is associated with low-density sedimentary rocks within the Rio Grande graben, New Mexico (loc. 10). Structural relief on the graben can be determined from the gravity data in terms of estimated densities. Uncertainty about the effect of compaction, however, and the unknown thickness of intermediate-density pre-Tertiary sedimentary rocks affect the calculations by many thousands of feet. A system of analysis based on an exponential density–depth function involving assigned coefficients is used by L. E. Cordell both to simulate the effect of compaction and to remove the problem of basal stratigraphy (by making the density of the Tertiary and pre-Tertiary rocks equivalent beyond a given depth). The model tends to exaggerate deep structure so that the positions of the main graben border faults are brought out more sharply. In the Albuquerque area, these faults appear to occur considerably inward from the graben border as determined by surface mapping. In general, the analysis provides quantitative, sometimes stringent, limitation on the resolving power of gravity data over thick sedimentary basins.

Reverse fault links in South Park, Colo.

Mapping in the Jefferson quadrangle, Colorado (loc. 11), by D. G. Wyant and Fred Barker shows that high-angle reverse faults stratigraphically displace folded beds of Jurassic to early Tertiary age as much as 11,000 feet. These faults apparently link the Elkhorn thrust, which lies along the eastern margin of South Park, to the Williams Range thrust, which extends northward from the park. These results clarify a problem of many years standing in Colorado geology.

IGNEOUS ROCKS

Lincoln County laccolith, New Mexico

A probable laccolith of monzonite porphyry about 25,000 feet across, with a maximum thickness of 2,500 feet, has been recognized by Kenneth Segerstrom in the central part of the Jicarilla Mountains, Lincoln County, N. Mex. (loc. 12). The laccolith is now largely unroofed, but exposures on its flanks indicate that a domed and wrinkled pile of sills about 2,500 feet thick, including intervening sedimentary layers, formerly covered the main intrusion. Individual sills range in thickness from 1 or 2 feet to 500 feet. Other apophyses, 1 mi or more across and at least 500 feet thick, which may also be laccoliths, ring the main intrusion. Dikes are virtually absent in the concordant intrusive complex and intruded sedimentary rocks.

McClure Mountain intrusive complex, Colorado

An anomalous magnetic high in the southwestern part of the McClure Mountain Complex of gabbro-syenite intrusive rocks (loc. 13) about 15 mi northwest of Westcliffe, Colo., was found by a low-altitude airborne magnetometer survey. Geologic mapping by R. L. Parker suggests that this anomaly is caused by the presence of bodies of gabbro and pyroxenite complexly intruded and altered by syenite. The anomaly is about the same magnitude as that caused by the similar mafic-ultramafic group of rocks at Iron Mountain on the east side of the McClure Mountain Complex. It thus seems that the complex has a more symmetrical structure than originally thought. Early mafic-ultramafic rocks once occupied most of the present area of the complex but were centrally intruded and shouldered aside by the later syenite magma.

STRATIGRAPHIC STUDIES

Permian sedimentary rocks derived from McClure Mountain Complex, Colo.

Local details of Permian paleogeography in the Wet Mountain Valley, south-central Colorado, have become more clear following the discovery by G. R. Scott of coarse clasts of biotite-hornblende syenite, nepheline syenite, coarse biotite syenite, and fenitized granitic gneiss in red beds of the Sangre de Cristo Formation (Pennsylvanian and Permian) at Goat Creek, 10 mi west-northwest of Westcliffe. The Sangre de Cristo beds are composed of poorly sorted arkosic conglomerate, grit, and sandstone chiefly made up of debris weathered from Precambrian crystalline rocks. The seyenite and fenite are inferred to have been derived from the McClure Mountain Complex (Lower Cambrian) and its altered borders, a conclusion made more positive by the unique rock types known in this area only from this single mass. The tectonic trough in which the Sangre de Cristo Formation was deposited was bordered by northwesterly faults of presumed Precambrian ancestry. Paleozoic tectonism is marked by renewed activity on these faults. In the Permian, streams flowed southwesterly across a highland from the McClure Mountain area to Goat Creek, as shown by a train of syenite debris about 15 mi long. Although sought, the syenitic debris has not been seen in the red beds either north or south of the Goat Creek locality at the eastern base of the Sangre de Cristo Range, thus implying dilution by streams bearing Precambrian debris into and within the Permian trough.

Paleocene rocks in northwest Colorado

Mapping by W. J. Hail, Jr., in the Smizer Gulch and adjacent quadrangles, Rio Blanco and Moffat Counties, Colo. (loc. 14), shows that rocks lying above coal-bearing Mesaverde Group (Cretaceous) rocks and below variegated claystones of the Wasatch Formation (Eocene) can be separated into an upper dark shale unit and a lower claystone and sandstone unit. The upper unit and at least part of the lower unit are probably Paleocene in age, based on a preliminary examination of fresh-water mollusks by W. A. Cobban.

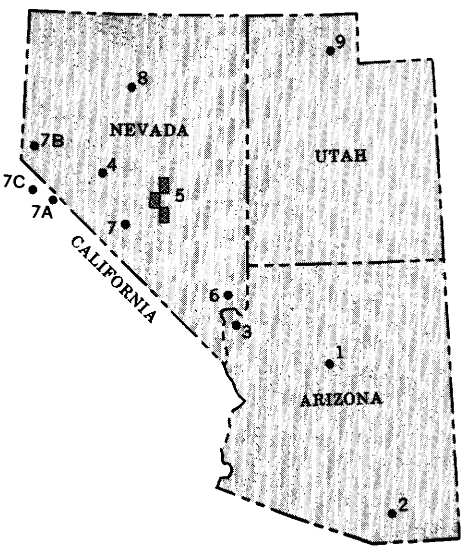
Possible aquifer in Mancos Shale

A 200-foot, fine-grained marine sandstone in the main body of the Mancos Shale (Upper Cretaceous) appears to be widespread near Lamy, N. Mex. (loc. 15), according to G. O. Bachman. The sandstone may be the continuation of one of the Upper Cretaceous sandstones extending eastward from the San Juan basin and may be important locally as an aquifer.

BASIN AND RANGE REGION

Geochronology of physiographic history of the southern part of the Colorado Plateaus

Detailed studies of the distribution and K-Ar dating of basaltic flows in north-central Arizona (locality 1, index map) by E. H. McKee and C. A. Anderson have clarified the time



STATES IN BASIN AND
RANGE REGION

sequence of the late Cenozoic physiographic development of the southern part of the Colorado Plateaus. Prior to and during the time of basaltic vulcanism, the drainage in the region was north and northeast across what is now the Verde Valley. The oldest basalts are 10 to 15 m.y. old. Major displacement on the Verde fault offset these older basalts, forming the western margin of the Verde Valley, which grew northward by headward erosion. Some basalts on the Mogollon Rim north of the Verde Valley are about 8 m.y. old, indicating that between 8 and 10 m.y. ago the prevailing drainage changed from northward to southward, marking the beginning of uplift along the southern part of the Colorado Plateaus relative to the Basin and Range province. Lava flows about 5 m.y. old flowed down canyons cut in the Mogollon Rim, indicating that much of the southern part of the Colorado Plateaus had been dissected 5 m.y. ago. Most of the basalts are alkali-olivine basalts, similar to many other basalts in the Western United States.

Sedimentary breccia, southeastern Arizona

The Pantano Formation, which is an Oligocene-Miocene basin deposit in southeastern Arizona (loc. 2), contains three sedimentary breccia beds in the rocks of Miocene age, according to T. L. Finnell. The breccia beds contain blocks of Precambrian quartz monzonite, and Bolsa Quartzite and Abrigo Limestone (Cambrian); they thin to a feather edge southward and westward away from the Rincon Mountains, here considered as the source area. The breccia beds are believed to be gravitational slides that originated when the gneiss, now exposed in the Rincon Mountains, still had a mantle of lower Paleozoic sediments.

Laramide lode gold in Gold Basin—Lost Basin district, Arizona

Hydrothermal muscovite in the gangue of a typical gold-quartz vein has yielded a K-Ar isotopic age, obtained by E. H. McKee (written commun., 1970), indicating a Late Cretaceous age for the lode mineralization in the Gold Basin--Lost Basin district south of Lake Mead in Arizona (loc. 3), according to P. M. Blacet. Previously the system of gold-bearing veins was considered of probable Precambrian(?) age. The revised Laramide age closely approximates the time of emplacement of porphyry copper and related vein deposits in the Mineral Park area 35 mi to the south.

Phelps-Stokes iron deposit, Nevada, associated with magnetic anomaly

East of Gabbs, Nev. (loc. 4), W. E. Davis identified a positive magnetic anomaly of 400 to 500 gammas associated partly with the Phelps-Stokes iron deposit near Bell Canyon. The region is underlain by upper Paleozoic volcanic rocks and Triassic sedimentary rocks that have been deformed and invaded by stocklike bodies of quartz monzonite of Mesozoic age and dikes of Tertiary age. Iron ore, principally magnetite with minor amounts of hematite, was deposited in dolomite of the Luning Formation of Late Triassic age near a mafic dike that was intruded along a fault between the volcanic and sedimentary rocks.[63] Although considerable ore has been mined, sufficient disseminated magnetite and pyrrhotite probably remains to cause a magnetic maximum over the deposit. The trend of the anomaly suggests that mafic dike rock, and perhaps the iron-bearing rocks, extend southeastward to underlie tuffs and alluvium marked by maximums on the east front of the Paradise Mountains.

Left-lateral strike-slip faults and related metallization in southeastern Nevada

E. B. Ekren and W. D. Quinlivan have recognized several zones of northwest-trending strike-slip faults in the Reveille, Tybo, and Moores Station 15-minute quadrangles (loc. 5), southeastern Nevada. The displacement is left lateral at Tybo and probably also at Reveille. Zones of hydrothermal alteration occur in, or near, these fault zones, and high-grade stibnite deposits are localized in normal faults adjacent to the major strike-slip fault zones in all three localities.

From the relations between the strike-slip faults and igneous rocks of different age, the major strike-slip displacement occurred between 18 and 27 m.y. ago. At Reveille about 10 mi of strike-slip displacement occurred in 27-m.y.-old welded tuff, whereas dikes of 18-m.y.-old quartz latite, intruded in several areas along the principal strike-slip faults, show little or no offset. The strike-slip faults also served as loci for extensive eruption of 5- to 10-m.y.-old basalts, which at one time covered the entire northern part of the Reveille Range and today cover about 60 sq mi on the east and west flanks of the range.

Left-lateral strike-slip faults, southeast Nevada

According to studies by R. E. Anderson, a northeast-trending left-lateral strike-slip fault in Nevada north of Lake Mead (loc. 6) cuts a clearly distinct volcano into two parts and offsets them by 12 mi. The faulting postdates a 12.6±0.8-m.y.-old lava (K-Ar isotopic age) from the upper part of the volcano. Reconnaissance mapping in the surrounding area indicates that the fault is part of the left-lateral strike-slip fault system on which the cumulative late Tertiary offset appears to be at least 40 mi.

Isotopic ages of mineralization, Nevada-California

K-Ar isotopic ages of host rocks, altered wallrocks, and gangue minerals associated with ore in the volcanic sequences of western Nevada and eastern California (loc. 7, 7A, 7B, 7C) have shown, according to M. L. Silberman, that the epithermal gold- and silver-bearing quartz veins were emplaced in volcanic rocks of Miocene and Pliocene age. The usual relations show an altered and mineralized dacitic host rock for which the mineralization either overlapped or occurred very shortly after the end stages of the volcanic activity. The dispersion of K-Ar dates suggests that the process of mineralization takes place over a finite interval of time, on the order of about a million years. In general, the dacitic host rock is succeeded by volcanic rocks of different chemical affinity, either a basalt-rhyolite sequence or an alkalic sequence. The ages of ore deposition from the K-Ar measurements are: Goldfield—20 to 21 m.y. (alunite), Bodie—7 to 8 m.y. (adularia), Comstock—12.5 to 14 m.y. (adularia), and Monitor—4.5 m.y. (sericite).

Propylitic, argillic, and alunite-quartz alteration, Virginia City, Nev.

According to D. H. Whitebread the hydrothermal alteration in the dacite of the Kate Peak Formation penetrated by four drill holes near Virginia City, Nev. (loc. 7B), comprises three main types: propylitic, argillic, and alunite-quartz. These three alteration types are found at different depths and in places are adjacent to fresh dacite. The argillic alteration is subdivided

[63] Reeves, R. G., Shawe, F. R., and Kral, V. E., 1958, Iron ore deposits of Nevada: Nevada Bur. of Mines Bull. 53, pt. B, p. 44.

into a montmorillonite zone and a kaolinite zone. Rocks that have undergone only weak propylitic alteration are distinguished from fresh dacite by alteration of the ferromagnesian minerals and by secondary calcite which, in part, replaces plagioclase. The change from propylitic to montmorillonite alteration is gradational, and much of the propylitized rock contains considerable montmorillonite. The kaolinite zone borders an innermost alunite-quartz zone.

Age and geochemistry of alteration, Copper Canyon porphyry copper, Nevada

Intrusions spatially and genetically related to the Copper Canyon porphyry copper deposit, Nevada (loc. 8), have been altered pervasively by late magmatic or early postmagmatic fluids, according to T. G. Theodore. District-wide chemical and petrologic studies of plutons (both altered and unaltered) suggest, however, that many of the altered intrusions were originally granodiorites. They are now quartz monzonites, both modally and chemically. Alteration trends in the rocks primarily involve progressive leaching of CaO and addition of K_2O; rubidium contents follow potassium, and strontium contents follow calcium. Metallization is middle Tertiary, as K-Ar isotopic ages determined by M. L. Silberman on hydrothermal biotite and K-feldspar in whole rock are late Eocene or early Oligocene. In addition, fluid-inclusion studies completed by J. T. Nash (r1570) stress the importance of dense chloride brines during metallization. Finally, the most economically substantial ore zones in the porphyry deposit are restricted to formerly hematite-rich zones of the Battle Formation (Middle Pennsylvanian). This implies that redox reactions involving hematite were significant in the development of the ore.

Eastward movement on the Golconda thrust, Nevada

At Copper Canyon, in the Antler Peak quadrangle, Nevada (loc. 8), abundant outcrop-scale structural data were gathered by T. G. Theodore from the Pumpernickel Formation (Pennsylvanian(?)) in the upper plate of the Golconda thrust—a regionally extensive structural feature of the Sonoma orogeny. In these rocks, diagrams of poles to bedding surfaces define girdles whose β axes trend slightly east of north and are approximately horizontal. Stereographic plots of all axial structures (lineations, bedding plane crenulations, fold axes) form a strong single maximum that plunges 5° at N. 5° E. The axial structures are statistically parallel to the β axes defined by the bedding planes. These axial structures also have monoclinic symmetry and define a B axis (axis of rolling). Furthermore, the fold forms indicate shear displacements on the bedding planes, normal to the fold axes, as the dominant type of tectonic transport recorded in the Golconda plate. As the folds are consistently overturned toward the east, therefore, the apparent horizontal component of tectonic transport in the Golconda plate at Copper Canyon has an azimuthal bearing of 95°—that is, toward S. 85° E. This inferred direction of transport should not be extrapolated to other areas; many similar studies elsewhere are needed to adequately resolve the geometry of such a regionally extensive thrust plate.

Volcanic history of the Bodie Hills, California-Nevada

F. J. Kleinhampl and M. L. Silberman report that the volcanic uplands of the Bodie Hills, California-Nevada (loc. 7A), were constructed in two great pulses of igneous activity. The first one dates from approximately 12 m.y. to 8 m.y. and produced great volumes of calc-alkaline pyroclastics and flows that originated from several discrete volcanic centers. The end stage of this igneous activity was marked by emplacement of the gold-bearing adularia-quartz veins at Bodie. The second pulse occurred from approximately 5 m.y. ago to very recently and produced volumes of alkalic-calcic flows, domes, and plugs, including many young alkali-olivine basalts. The two volcanic fields overlap near Bodie, but the former occupies most of the area west of Bodie (the Bodie Hills proper), and the latter occupies the area east of Bodie (Cedar Hills—Trench Canyon, Aurora area).

Structural history of Goldfield, Nev.

R. P. Ashley has found three pre-alteration, pre-ore fracture systems that dominate the structural geology of the Goldfield mining district, Nevada (loc. 7). The oldest is a ring fracture system whose existence is inferred from the distribution of pre-alteration volcanic rocks and the locations of known and probable vent areas for these rocks. This fracture system is completely covered by the volcanic rocks, but locally renewal of movement has apparently caused new fractures to develop in the overlying volcanic rocks along the trend of the old fracture system. The second important fracture system, which is a younger fracture zone half a mile wide, trends eastward from the main mining district. The third system is a series of step or block faults which have northerly trends and easterly dips; the fault blocks dip west and are successively downdropped to the east. The east-west fracture zone and the step faults are about the same age, and the east-west fracture zone forms the boundary between two terrains: dominantly northwest-trending step faults to the south, and dominantly north- to northeast-trending step faults to the north. Movement on the step faults has a rotational aspect; dips on some of these faults are quite low, and opposing bedding dips in the adjacent fault blocks quite high. Several step faults coincide with the inferred western side of the ring fracture zone.

The major ore bodies occur where the coincident ring fracture and step fault systems intersect the large east-west fracture zone. Distribution of ore bodies and anomalous but subeconomic amounts of minor elements in altered rocks indicates that metallization is associated with the ring fracture, and the northerly trending faults and east-west fracture zone act as secondary structural controls for ore deposition. If this interpretation is correct, exploration possibilities can be defined for various parts of the Goldfield altered area.

The significance of the east-west fracture zone and its associated northerly trending faults is not yet known, but they are apparently related to tectonic and volcanic activity that affected an area substantially larger than the Goldfield altered area. North- to northeast-trending basin-range faults did not develop until at least 2 to 4 m.y. after alteration and ore deposition. Basin-range faults trending toward the Goldfield altered area die out at its margins.

Eastward transport on the Willard thrust, Utah, confirmed

Recent mapping by M. D. Crittenden and M. L. Sorensen in the type area of the Willard thrust east of Ogden, Utah (loc. 9), has shown that this east-dipping fault is underlain by a recumbent nappelike syncline, overturned toward the east. The fold is exposed over an area of at least 10 sq mi and involves rocks ranging in age from Cambrian to Mississippian. Both limbs dip eastward; hence the upper limb has been rotated more than 180°. This large structure, together with many smaller ones in both the upper and lower plates of the thrust, confirm beyond doubt that the thrust moved from the west, as indicated by regional facies relations in many units of both Precambrian and Paleozoic age.

Cordilleran miogeosyncline in northwestern Mexico

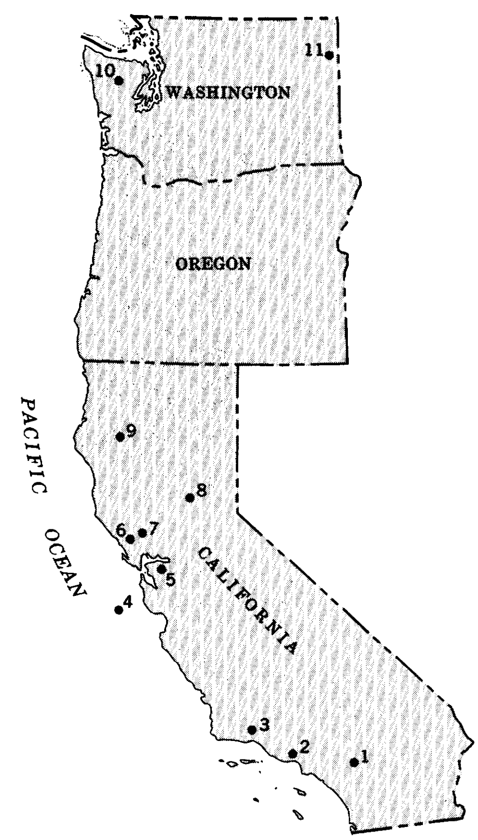
Stratigraphic studies in the Caborca region, Sonora, Mexico, by F. G. Poole and P. T. Hayes, show that lower and middle Paleozoic strata are remarkably similar to time-equivalent strata in the northern Death Valley region of southeastern California. They were deposited in similar miogeosynclinal environments. Much thinner sections of time-equivalent cratonic strata in the intervening areas of western Arizona and adjacent California were deposited on a stable continental platform bordering the area. The distribution pattern of the thick miogeosynclinal sections and the intervening thin cratonic sections suggests a major change in strike of the Cordilleran geosyncline between Death Valley and Caborca. The miogeosynclinal strata of the Caborca region apparently represent a remnant of the southern part of the Cordilleran miogeosyncline east of the zone of continental rifting that obliquely truncated the geosyncline and bordering craton in California.

PACIFIC COAST REGION

CALIFORNIA

Compression on part of the San Andreas fault

In southern California the San Andreas fault normally trends about N. 60° W. and had right-lateral movement during Quaternary and probably Tertiary time. In the San Bernardino Mountains (locality 1, index map), however, its major (north) branch trends nearly east-west (N. 75° W.) for 35 mi westward from its juncture with the east-trending 50-mi-long Pinto Mountain fault, which had left-lateral movement in Quaternary time. According to T. W. Dibblee, Jr., evidence of right-lateral movement during Quaternary time is lacking on the anomalously trending portion of the San Andreas fault even though it is clearly evident on other parts. The anomalous trend and halting of right-slip movement is attributed to pressure from left slip on the intersecting Pinto Mountain fault. During Quaternary time the San Bernardino Mountains were uplifted along both that part of the San Andreas fault and part of the Pinto Mountain fault. This great uplift is attributed to conversion of strike-slip movements to severe compressive movements nearly at right angles to the anomalous portion of the San Andreas fault.



PACIFIC COAST STATES

Structural evolution of the Santa Monica Mountains

A geologic reconstruction of the Santa Monica Mountains–Los Angeles basin area (loc. 2) by R. H. Campbell (r1079) and R. F. Yerkes (r1107) shows that an orderly depositional framework characterized by north-trending shorelines prevailed from Late Cretaceous through early Miocene time, but that in middle Miocene time the old shorelines were abruptly offset about 90 km in a left-lateral sense along the east-trending southern boundary fault system of the Transverse Ranges province. This shearing was accompanied by tension which gave rise to the earliest discrete depositional basin in the Los Angeles area, south-moving detachment fault plates, and extensive andesitic and basaltic volcanism. Subsequent north-south compression has resulted in north-over-south reverse faulting at the southern boundary of the western Transverse Ranges, accompanied by right-lateral slip on the northwest-trending Newport-Inglewood and Whittier zones. This reconstruction is in close agreement with the chronologic sequence of events predicted by the tectonic model of Atwater,[64] in which uniform relative motion of major crustal plates results in a specific chronologic sequence of changing regional stresses at the western margin of the North American continent.

New find of Tertiary rocks, San Rafael Mountains

Geologic mapping by J. G. Vedder and R. D. Brown, Jr., in the upper Mono Creek district of the San Rafael Mountains (loc. 3) has revealed small downfaulted and infolded remnants of upper Tertiary strata that lie unconformably on an exceptionally thick succession of Upper Cretaceous and Eocene sedimentary rocks. The distribution, faunal content, and lithofacies relations of the younger rocks require reinterpretation of regional Oligocene-Miocene paleogeography and paleoenvironments. This upper Tertiary section is disrupted by two unconformities and is separated from the Eocene sequence by a major discontinuity. Nonmarine Oligocene(?) beds at the base of the younger succession contain locally derived detritus that suggests dual source terranes both to the southwest and northeast. The nonmarine beds are overlain by transgressive marine sediments of early and middle Miocene age. Slow deposition prevailed through middle Miocene time under moderately deep open-sea conditions that presumably extended over a much larger area than was previously supposed. A regressive phase that began in late Miocene time with the deposition of sublittoral clastic strata culminated with nonmarine sedimentation in a local trough that may have been structurally controlled by the Big Pine fault.

Geomagnetic studies

Three-dimensional model analysis by computer was applied by Andrew Griscom to a confusing magnetic anomaly associated with the Guide Seamount, 60 mi offshore from San Francisco at the foot of the continental slope (loc. 4). The analysis shows that the bulk of the anomaly is caused by a thick apron of flows surrounding the seamount and mostly buried by muds, and that only a small amount of the anomaly is caused by the conical submarine mount itself. Not only does the flow apron have a greater volume than the mountain, but it also has a considerably greater apparent magnetization.

A similar analysis was made of a large magnetic anomaly over Mount Diablo, 30 mi east of San Francisco (loc. 5), which in addition has an associated gravity high of about 60 mgal. Diabase at the north end of the mountain appears to be the rock unit causing both anomalies. Preliminary calculations indicate that the form of the diabase mass is crudely tabular and approximately conformable with a folded thrust contact between Franciscan Formation rocks and the Great Valley sequence. This mass may be similar to remnants of oceanic crust described elsewhere along the Coast Range thrust by E. H. Bailey (r0160), M. C. Blake, Jr., and D. L. Jones.

Revised age of Merced(?) Formation of Sonoma County, Calif.

Revision of age assignment and correlation of the Merced(?) Formation is necessitated by molluscan fossils that J. A. Bartow and W. O. Addicott recently collected from several localities north of San Francisco Bay. In the Healdsburg quadrangle (loc. 6) near the present northeastern limit of the Merced(?) Formation, earlier collections from one locality indicated a late Pliocene age for the Merced(?), and it was considered to be entirely younger than the Petaluma Formation (lower Pliocene). New collections from this same locality and another nearby locality confirm that age. However, faunas from the Merced(?) Formation at two localities to the southwest in the Sebastopol area are probably early Pliocene in age. The Merced(?) Formation of Sonoma County thus ranges in age from early to late Pliocene and is probably partially equivalent in age to the Petaluma Formation.

Age of Sonoma Volcanics, northern Coast Ranges

E. A. Mankinen collected samples from 30 units within the Sonoma Volcanics for paleomagnetic studies and K-Ar age determinations. Age determinations show that the majority of these units are late Pliocene in age. Parts of the Gauss normal and Gilbert reversed-polarity magnetic epochs are represented, with ages from 2.9 to 5.2 m.y. The youngest units sampled are rhyolites of Mount St. Helena (loc. 7) which all formed during the Gauss normal epoch. Lavas and welded tuffs from the Mayacmas Mountains east of Santa Rosa and from the Howell Mountains east of Napa all formed during the Gilbert reversed epoch. An age of 11.8 m.y. was obtained from other rocks near the base of Burdell Mountain, north of Novato, and shows that rocks of an older volcanic period also have been mapped as part of the Sonoma Volcanics. The number of units which may have formed during this period was not determined.

Bouguer anomalies in the northern Sierra Nevada

The reduction and compilation of about 2,000 new gravity stations located in the Sierra Nevada north of Sacramento (loc.

[64] Atwater, Tanya, 1970, Implications of plate tectonics for the Cenozoic evolution of western North America: Geol. Soc. America Bull., v. 81, p. 3513–3536.

8) were completed by H. W. Oliver. Bouguer anomaly maps show that the strong eastward decrease in gravity characteristic of the southern Sierra Nevada persists to the north but decreases gradually from about 180 mgal near Sacramento to about 100 mgal east of Chico. Gravity lows of about 50 mgal are associated with the Rocklin and Big Bald Rock plutons and indicate a depth extent for these granitic rocks of 10 to 15 km. The Rocklin anomaly extends 25 km westward into the Sacramento Valley north of Sacramento and delineates an arcuate buried contact of the pluton with the pre-Cretaceous metamorphic rocks. Gravity anomalies over other granitic masses in the northern Sierra Nevada are much smaller (20 mgal) and indicate that these masses are more mafic at depth and probably not very thick. The eastern half of the Bucks Lake pluton south of Mount Lassen causes a gravity high in contrast with surrounding Jurassic-Triassic metavolcanic rocks.

Southern Klamath Mountains

The approximate position of a north-trending Early Cretaceous shoreline has been located by D. L. Jones (r1578) and W. P. Irwin in the southern Klamath Mountains (loc. 9) on the basis of a transition from nonmarine to marine strata at Glade Creek and Big Bar. The shoreline is truncated at the south end of the Klamath Mountains by a west-northwest-trending fault zone, and its southern continuation lies 60 mi or more to the east where it is concealed beneath younger rocks of the Great Valley. Displacement of the shoreline is thought to have resulted from left-lateral tear faulting in the upper plate of the Coast Range thrust, contemporaneous with eastward underthrusting of the lower (Franciscan) plate. The westward bulge of the Klamath arc also may have resulted from this faulting, as the amount and direction of the bulge is comparable with the displacement of the Early Cretaceous shoreline.

Of related paleotectonic interest, an andesitic volcanic formation has been traced for a distance of 50 mi through the southern Klamath Mountains by W. P. Irwin. It extends from the Cretaceous overlap at the western edge of the Great Valley in the Chanchelulla Peak quadrangle to beyond the Trinity River in the Ironside Mountain quadrangle and, with associated formations, forms a lithic belt about 5 mi in width. The andesite is overlain by argillite, thin-bedded chert, volcanic rocks, and limestone lenses. Fossils found in a few of the limestone lenses suggest a late Carboniferous or Early Permian age. The andesite formation is tentatively correlated with the Taylor Meta-Andesite, which crops out about 80 mi to the east at the north end of the Sierra Nevada.

WASHINGTON

Olympic Peninsula

The mountainous core of the Olympic Peninsula (loc. 10) is partially ringed by the predominantly basaltic Crescent Formation of early and middle Eocene age. Within this volcanic horseshoe, open to the west, are partially arcuate, northwest-trending belts of highly sheared rocks.[65] Core units now mapped by W. M. Cady, R. W. Tabor, and R. J. Stewart are delineated by the relative abundance of graywacke or slate and the amount of penetrative deformation. The core belts are bounded on the north by the east-west-trending Calawah fault zone and on the southeast by a major southwest-trending tectonic zone. One graywacke-rich core belt appears to grade into Foraminifera-bearing Eocene to Oligocene graywackes, although much of the core terrane is separated from less intensely sheared Tertiary sedimentary rocks to the west by a mile-wide, slate-rich tectonite zone.

Core rocks bearing prehnite and pumpellyite grade westward into laumontite rocks, whereas eastward they grade into low-rank greenschists. K-Ar age analyses of metamorphic rocks of the core indicate regional metamorphism about 29 m.y. ago, followed by local recrystallization associated with faulting and the formation of quartz veins about 17 m.y. ago.

Newport fault zone

A large zone of shearing was discovered by F. K. Miller during mapping of the Newport 30-minute quadrangle in northeastern Washington (loc. 11) and was traced more than 35 mi. At the north end of the quadrangle the zone, named the Newport fault zone, strikes roughly north-south and dips about 30° E. Near the center of the quadrangle the zone bends toward the east and maintains a strike of about N. 70° W. to the town of Newport. On this segment, the zone dips about 45° to 50° NE. The terrane west of the fault zone is composed of plutonic and high-grade metamorphic rocks, and to the east it contains unmetamorphosed Belt Supergroup and Paleozoic strata. The fault zone cuts the 50-m.y. Silver Point Quartz Monzonite and is overlain by the Tiger Formation. An upper limit for the age of faulting may be provided if plant fossils found in the Tiger Formation are datable. Extensively brecciated rocks in the upper block contain anomalous amounts of sulfide minerals, suggesting that the Newport fault zone may be important as a control for localization of mineral deposits.

Two episodes of plutonic igneous activity in the Newport quadrangle have been identified at about 100 m.y. and 50 m.y. ago. During each of these episodes, plutons of both two-mica and hornblende-biotite compositions were intruded. These two fundamentally different petrologic suites are probably not genetically related. The 50-m.y. two-mica rocks are chemically and petrologically identical with the 100-m.y. two-mica ones. Plutons of one period cannot be distinguished from plutons of the other on the basis of appearance or chemistry. One hypothesis under consideration is that the two-mica rocks may be derived from melting of the lower part of the Belt

[65] Tabor, R. W., Cady, W. M., and Yeats, R. S., 1970, Broken formations and thrust faulting in the northeastern Olympic Mountains, Washington [abs.]: Geol. Soc. America Abs. with Program, v. 2, no. 2, p. 152.

Supergroup and from any underlying sedimentary or metamorphic rocks.

ALASKA

New scientific and economic findings of significance have resulted from many diverse field and topical investigations carried out in Alaska during the past year. Discussions of these findings are divided into six parts corresponding to six major regions. Locations of the regions and of the specific study areas are shown on the accompanying index map of Alaska.

NORTHERN ALASKA

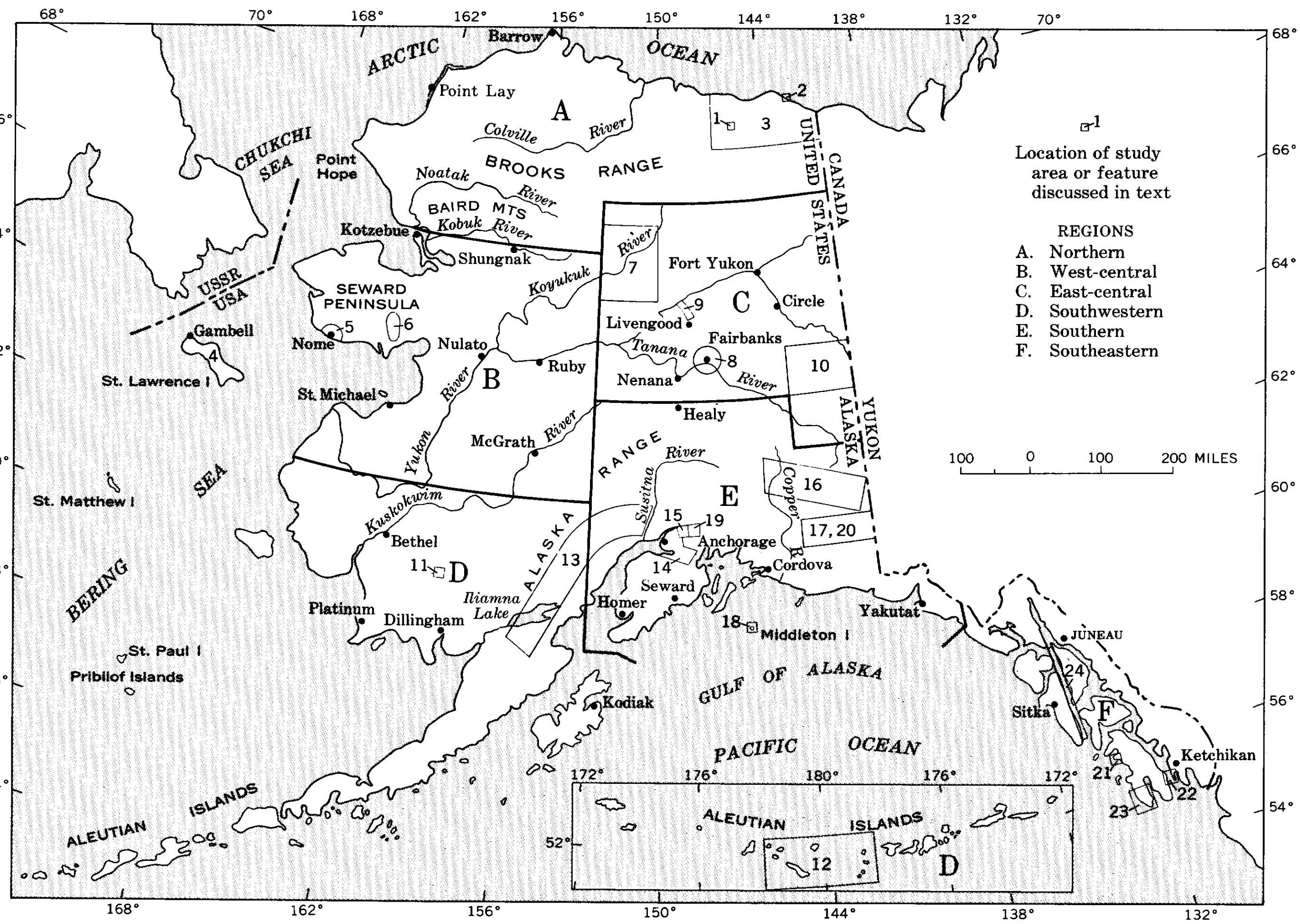
Oldest fossils from northern Alaska

Cambrian fossils have been found in the volcanic-carbonate member of the Neruokpuk Formation on Marsh Fork in the Mount Michelson quadrangle (locality 1, index map) and near the Aichilik River in the Demarcation Point quadrangle (loc. 2). Olenellids from Marsh Fork were recognized as Early Cambrian by J. T. Dutro, Jr., in the field. The identification was verified by M. E. Taylor and A. R. Palmer, who suggest resemblance to *Olenellus praenuntius* Cowie from the Canadian Arctic. Trilobites from the Aichilik area are assigned to the Late Cambrian (Franconian) by Palmer. The characteristic Late Cambrian brachiopod *Billingsella* also occurs there in great abundance. These are the first definitive fossils from the Neruokpuk Formation, a complex unit that lies unconformably below the Carboniferous in northeastern Alaska.

Highlights of reconnaissance mapping in the northeastern Brooks Range

In addition to finding the oldest fossils in northern Alaska, the workers of the northeastern Brooks Range project (loc. 3) continued to define fundamental rock relationships in this previously little studied region that is adjacent to the Prudhoe Bay oil field.

Geologic mapping by H. N. Reiser, W. P. Brosgé and J. T. Dutro, Jr., substantiates the interpretation that the oldest rocks in the region occur in the structural highs of a dominantly gently folded pre-Mississippian erosion surface. These oldest rocks, presently grouped under the term Neruokpuk Formation, contain at least 10 mappable units of Precambrian(?) to Devonian age; also contained in the sequence are at least two pre-Mississippian unconformities.



In the Mount Michelson quadrangle the Neruokpuk consists of quartz wacke of Precambrian(?) age, extensive chert, intercalated volcanics and limestone of Cambrian age, and a limy sandstone-siltstone unit of probable Devonian or Silurian age; regionally, the sandstone-siltstone unit unconformably overlies the Precambrian(?) and Cambrian rocks.

A microfossil and rugose coral zonation of the Lisburne Group has been completed recently by A. K. Armstrong. Using detailed stratigraphic correlations provided by the zonation, Armstrong was able to show that two carbonate depositional cycles are represented in the major northward transgression of the Lisburne in the Mount Michelson area: a fairly large transgression on late Meramec-early Chester time, and a regression on late Chester time. Before the close of Chester time, however, northward transgression resumed, culminating in open-shelf carbonate deposition.

Mapping in 1969 by H. N. Reiser (r0792) demonstrated the presence of a probable Jurassic Cretaceous unconformity which in the northern Sadlerochit Mountains locally cut down to the Sadlerochit Formation (Permian and Triassic).

Sixty miles to the southeast a uniquely gently folded syncline in the Demarcation Point quadrangle provided R. L. Detterman in 1970 the opportunity to measure approximately 5,000 feet of Mesozoic sedimentary rocks directly overlying the Sadlerochit Formation. Faunal evidence suggests that these rocks are not older than Cretaceous. This information serves as further evidence of the presence of at least local positive land areas during Late Jurassic time in the vicinity of the Romanzof Mountains.

H. N. Reiser and R. L. Detterman discovered oil-saturated siltstone and sandstone of probable Late Cretaceous age along the lower Jago River. The saturated exposures, which were only briefly examined, are probably 100 feet or more thick.

Ammonites discovered by W. P. Brosgé and J. T. Dutro, Jr., in Cretaceous wackes located 5 mi south of Kingak Cliff in the Mount Michelson quadrangle have been identified by D. L. Jones as *Paragastroplites spiekeri* of mid-Albian Age. The discovery unquestionably demonstrates the presence of Nanushuk Group rocks in this area.

Arctic lower Paleozoic geosyncline

Highly deformed and weakly metamorphosed, predominantly siliceous rocks are exposed in the northeastern Brooks Range, Alaska, and the British-Barn Mountains of Yukon Territory, Canada. Originally, this fold belt and similar rocks in boreholes along the Arctic coast were considered as mainly Precambrian basement belonging to a craton or platform that extended still farther north into what is now the Canada basin. Instead, Michael Churkin, Jr.[66] (r0788), has interpreted these same rocks as part of a lower Paleozoic geosyncline.

More recently, the discovery in the northeast Brooks Range of Cambrian trilobites, the recognition of substantial amounts of mafic volcanics, and the dating of granitic plutons as Silurian, by H. N. Reiser, W. P. Brosgé, and J. T. Dutro, Jr., during 1969–70 fieldwork, lends support to the idea that the fold belt is a lower Paleozoic geosyncline deformed in the mid-Paleozoic.

This fold belt seems to continue west underneath the Arctic coastal plain. Slate, argillite, and graywacke in the bottoms of boreholes in the Prudhoe Bay oil field and farther west to Point Barrow probably represent continuations of the fold belt. These rocks form the basement of the Barrow arch, a broad structure of Mesozoic age that parallels the Arctic coast of Alaska.

Revised ranges of Cretaceous arctic Foraminifera

H. R. Bergquist concurs with W. V. Ramsay (British Petroleum of Alaska) that the *Caudryina tailleuri* faunal zone, long considered to be of early Albian Age, definitely occurs along with ammonites in beds of Late Jurassic age and with buchias in beds of Neocomian Age. The zone may range into the Aptian, but its Albian range is now doubtful.

In the Late Cretaceous, *Arenobulimina torula* Tappan, which with *Pseudoclavulina hastata* (Cushman) has been considered to be restricted to upper Turonian beds, is now known to range into the Senonian. *P. hastata*, however, appears to be a reliable indicator of the late Turonian.

Stratigraphic studies

Observations in the northern Richardson Mountains, east of the Mackenzie River Delta, and along the Yukon River between Eagle and Circle—at the invitation of Shell Canada, Ltd., the Polar Continental Shelf Project (Canadian Dept. of Energy, Mines, and Resources), and the Geophysical Institute of the University of Alaska—enabled I. L. Tailleur to compare rocks on Alaska's North Slope with those in northwestern Arctic Canada and east-central Alaska. Devonian to Cretaceous rocks in the three provinces are remarkably similar; thus coeval environments must have been closely related or connected despite the present right-angle bend of tectonic elements entering Alaska from Canada.

One striking similarity is the persistence of nearshore clastic deposits from the Prudhoe Bay area—where they are the major petroleum reservoir—to the northeast Brooks Range, through the Richardson Mountains in Canada, and to the Yukon River in Alaska. In all outcrop regions, distinctive coarse clastic beds with the trace fossil *Spirophyton* overlie carbonate beds with brachiopods identified as mid-Permian in age.

Other coeval lithogenetic units do not trace so continuously. Upper Devonian coarse clastic rocks, Mississippian and Pennsylvanian restricted marine deposits, Triassic condensed beds, Jurassic and lowermost Cretaceous distal deposits, and mid-Cretaceous orogenic rocks on the Yukon match facies of corresponding ages in the Brooks Range but not in the Richardson Mountains. Offshore and nearshore Jurassic and lowermost Cretaceous deposits in the northern Richardson

[66] Churkin, Michael, Jr., 1969, Paleozoic tectonic history of the Arctic Basin north of Alaska: Science, v. 165, p. 549–555.

Mountains seem to match more northerly facies of rocks of the same age on the North Slope.

The Late Cretaceous unconformity and transgression persists westward at least from Saskatchewan to the Arctic coast. In the Smoking Hills, about 200 mi east of the Mackenzie River, organically rich shale with bentonite on the unconformity seems to correlate with black shale and pyroclastic beds in the northeast Brooks Range; a probable westward equivalent is a section of paper shale and bentonite in the subsurface of the Naval Petroleum Reserve.

Observations also suggest eastward and southward persistence of the Brooks Range tectonic style of juxtaposed rock sequences. In the Richardson Mountains a Paleozoic carbonate buildup surrounded by coeval basinal deposits resembles known allochthonous carbonates to the west and could be a carbonate facies tectonically juxtaposed against the coeval basinal facies. Between Circle and Eagle on the Yukon River, possibly juxtaposed facies are Jurassic(?) mafic and Devonian carbonate rocks against Jurassic basinal and Devonian near-shore and basinal deposits.

WEST-CENTRAL ALASKA

Cretaceous plutons of St. Lawrence Island

Investigations by Béla Csejtey, Jr., W. W. Patton, Jr., and T. P. Miller (p. D68–D76) on St. Lawrence Island in the northern Bering Sea (loc. 4) reveal the presence of six major plutonic bodies with a combined area of about 350 sq mi. The plutonic rocks are dominantly quartz monzonite but include minor amounts of granodiorite, monzonite, and syenite.

The plutons occur as discordant bodies intruding folded but unmetamorphosed Paleozoic and Mesozoic carbonates and andesitic volcanics. Inhomogeneity within individual plutons may indicate emplacement by a successive series of magma intrusions of diverse composition.

Several deposits of molybdenum, copper, lead, and zinc sulfides have been found in and around the plutonic bodies in the western part of the island.

K-Ar age determinations on three of the six plutons date the intrusions as mid-Cretaceous (about 100 m.y.). Plutons of similar age, composition, and structural features are widespread in west-central Alaska and also appear to be present on the Chukotsky Peninsula, U.S.S.R.

Barite-fluorite-galena veins near Nome

Investigations by D. A. Brobst, D. M. Pinckney, and C. L. Sainsbury on a suite of samples from the barite-fluorite-galena veins of the Quarry deposit on the Seward Peninsula near Nome (loc. 5), suggest that the area is worthy of prospecting (see related study, p. D1–D8). The country rocks are sericite-chlorite schist and marble of the Nome Group of Precambrian age. These rocks are probably part of the upper plate of a thrust fault.

Petrographic work shows that the fluorite and barite have been sheared and recrystallized. Fluid inclusions, trapped during recrystallization, contain three phases: liquid water, liquid carbon dioxide, and gas. Upon heating, the inclusions homogenize at $245° \pm 3°C$. No evidence of boiling was found, indicating a depth of cover of at least several thousand feet.

The structure along with the relatively high temperature and pressure indicates a potentially large area of mineralization.

Alkaline subsilicic rocks in the Darby Mountains

Reconnaissance mapping in the southeastern Seward Peninsula by T. P. Miller, R. L. Elliott, D. H. Grybeck, and T. L. Hudson has revealed the presence of several alkaline subsilicic complexes in the Darby Mountains (loc. 6). These occurrences, together with similar rocks previously mapped in west-central Alaska, confirm the existence of a belt of alkaline subsilicic rocks extending for 180 mi in western Alaska. Mapping and sampling of the large plutons of the area, coupled with K-Ar ages, suggests the occurrence of at least three episodes of Mesozoic plutonic activity marked by rocks of definitive petrographic characteristics.

Fold belts of the northern Pacific basin

Around the rim of the northern Pacific basin, according to Michael Churkin, Jr., there are extensions of the fold belts of Alaska into the continent of Asia. A comparison of the stratigraphy within these fold belts shows a close correlation of depositional history not only for Cenozoic but also for Paleozoic and possibly Precambrian time. In evaluating continental drift in the Arctic there is no direct evidence for large-scale drift between Alaska and Chukotka, and the North American and Eurasian Continents apparently were connected across the Alaska-Chukotka Isthmus during the time of major drift in the Atlantic. The bends in various large-scale structures in Alaska and Chukotka may be in part results of compression in this narrow continental segment linking Eurasia and North America as the two continents separated across the Atlantic.

EAST-CENTRAL ALASKA

Ophiolites in the Bettles and Wiseman quadrangles

In the Bettles and southern Wiseman quadrangles (loc. 7) W. W. Patton, Jr., and T. P. Miller mapped a narrow belt of ophiolites extending for a distance of 250 mi along the northern and southeastern margins of the Yukon-Koyukuk province. The ophiolite assemblage, which includes pillow basalt, diabase, gabbro, ultramafites, and chert, is overlain by Lower Cretaceous volcanic rocks and graywacke and appear to rest on thrust fault contacts on metasedimentary rocks of Paleozoic and Precambrian(?) age. Foraminifera of Permian age (B. L. Mamet, oral commun., 1970) were found in a thin lens of limestone on pillow basalt and suggest a possible correlation of the ophiolites with the Rampart Group of the Yukon River valley.

Gold lodes of the Fairbanks district

As a result of field and laboratory work conducted largely by R. B. Forbes (USGS) and D. B. Hawkins (University of Alaska), approximately 5,000 samples have been collected and analyzed from the Fairbanks district (loc. 8), and a number of new gold anomalies have been found, including several as large as 200 ppm along the Ester Dome road. Statistical study of the analytical data has shown a useful correlation between gold and antimony in this district. Good correlations between gold and arsenic values could not be established because the present atomic-absorption method is not sensitive enough to yield meaningful values for arsenic.

The lode deposits of the Fairbanks district are mainly localized along the domed portions of the Cleary antiform. The antiform and the thrust fault underlying it are now recognized as one of the major structures of the district. The fault separates rocks of different metamorphic facies: a greenschist-facies schist and quartzite in the upper plate and an epidote-amphibolite facies with eclogitic rocks and amphibolites in the lower plate.

New find of Tertiary plant fossils from the Livengood quadrangle

Probable Tertiary (Eocene?) plant fossils were found by R. M. Chapman and W. E. Yeend in shale in several road cuts about 1 mi south of Isom Creek on the new pipeline haul road between Livengood and the Yukon River (loc. 9). This previously unknown Tertiary(?) section consists of shale, siltstone, graywacke, sandy granule conglomerate, pebble-cobble conglomerate, and some tuffaceous and cherty rocks, with interbedded amygdaloidal basaltic volcanic extrusive rocks. The beds dip 40° to 50° S. and are cut by many minor faults and fractures. The full extent of this unit could not be determined owing to the vegetation cover. It is apparently an east-trending infolded or infaulted block about 1 mi across strike and perhaps 2 to 3 mi in length surrounded by the Rampart Group rocks that are believed to be of probable Permian age. Other Tertiary sections exposed about 20 mi southwest on the Yukon River are clastic units with plant fossils, but they have no interbedded volcanic rocks. Final identifications of the fossil collections from near Isom Creek have not been completed.

Eagle quadrangle

A program of geologic mapping and mineral-resource investigation is continuing in the Eagle quadrangle (loc. 10) under the direction of H. L. Foster. Results to date bear on several important economic and geologic relationships.

Stream sediment samples collected in the northwestern part of the quadrangle contain somewhat higher concentrations of tin than found in other parts of the Eagle quadrangle. Analyses of rock samples suggest that leucocratic dikes which cut many of the granitic plutons may be a major source of the tin. Some dikes are pegmatitic and many others are porphyritic with smoky quartz phenocrysts. The dikes appear to be closely associated with felsic volcanic rocks and hypabyssal rocks of Tertiary(?) age.

Crinoid columnals were found in the Eagle A-3 quadrangle in white, fairly coarsely crystalline marble interlayered with quartz-biotite schist, quartzite, and amphibolite of the epidote-amphibolite or amphibolite facies. This is the first known occurrence of fossils in the higher grade metamorphic rocks of the Eagle quadrangle. The fossils are an indication of a Paleozoic age, as opposed to a Precambrian age, for the original sediments of at least some of the more highly metamorphosed rocks. It is now reasonable to expect that most of the metamorphic rocks of the Eagle quadrangle, particularly those with interlayered marble, are younger than Precambrian in age.

A partly serpentinized ultramafic body about ½ sq mi in area found in the Eagle B-3 quadrangle is unique in showing a clear relationship to the country rock. Layers and fingers of fine-grained green rock a few inches to several feet thick lie between layers and beds of marble. The ultramafic body was intruded into limestone; then, the ultramafic rock and limestone were deformed and metamorphosed. Because the marble in this area is probably Paleozoic in age, the ultramafic rock is probably also Paleozoic (rather than Mesozoic) in age. Other similar ultramafic bodies occur in localities scattered throughout the Eagle quadrangle, but their age and relationship to the country rock are obscure.

Remote-sensing experiments in permafrost

Areas not underlain by frozen ground were located along the route of the proposed trans-Alaska pipeline by means of airborne surveys measuring the quadrature component of the horizontal electric field of VLF waves. F. C. Frischknecht and W. D. Stanley also report that a combination of galvanic resistivity and variable frequency electromagnetic soundings appears to be an effective means of measuring the distribution of frozen ground in Alaska.

SOUTHWESTERN ALASKA

Mercury mineralization at the Cinnabar Creek mine

Geological and geochemical studies at the Cinnabar Creek mine and adjacent prospects (loc. 11) show that the vein minerals are primarily cinnabar, stibnite, and quartz with minor amounts of pyrite, sphalerite, dickite, gypsum, and dolomite. Native mercury is common throughout the deposit being studied by A. L. Clark, D. H. Sorg, J. M. Hoare, and W. H. Condon.

The deposits are emplaced within major fault zones and have a complex history of faulting, brecciation, and mineralization, including at least three phases of cinnabar emplacement.

Geochemical profiles transecting the main vein, by use of rock samples, indicate a depletion of Cu, Pb, Zn, and Mn associated with the fault zone and main vein. Rocks adjacent to the depleted zone show a marked concentration of Mn, Ba, Cu, and Fe. Rocks of the main vein are high in As, Hg, Sb, and Au content. Soil samples across the main vein area show anomalous concentration of Hg and As associated with the mineralized zone.

Trace-element studies show that native mercury contains only Au and Ag in detectable amounts, cinnabar contains anomalous concentrations of Au, As, Sb, and Zn, and stibnite contains anomalous amounts of Au, As, Hg, and Pb.

Geochemical profiles constructed from rock and soil samples appear to be effective guides for mercury exploration in southwestern Alaska.

Marine terraces of the western Aleutian Islands

Marine terraces of the western Aleutian Islands (loc. 12) are being studied by R. H. Morris in order to locate areas of geologically recent deformation. Results indicate that the present intertidal platform of the Rat and Delarof Islands groups has not been displaced by faulting in the last 4,000 yr. In the Rat Islands group, faulting has not affected either a marine terrace 3 to 5 m above sea level or a submerged platform 100 m below sea level believed to date from 17,000 yr ago. A southeastern component of tilt, however, is recognized on a higher terrace on Kiska Island, and a series of northeast-trending faults more than 130,000 yr old are recognized on Amchitka Island. In the Delarof Islands group the 3- to 5-m terrace may be uplifted several meters, and a higher terrace on Ulak Island is tilted southwards approximately 0.5°.

Recent faulting and tectonic adjustments have occurred on Attu Island, the westernmost of the Aleutian Islands; elsewhere west of Amchitka Pass, however, recent tectonic stability is inferred. Thus, although Amchitka Island is close to the seismically highly active Amchitka Pass area, the island appears to have been tectonically stable for the past 17,000 yr, and probably for the past 130,000 yr.

SOUTHERN ALASKA

Plutonic belts of the central and southern Alaska Range and the Alaska Peninsula

Investigations by B. L. Reed and M. A. Lanphere, using K-Ar mineral ages and reconnaissance mapping of approximately 30,000 sq mi of the central and southern Alaska Range and Alaska Peninsula (loc. 13), indicate that there were three major plutonic episodes during the Mesozoic and Tertiary. The first began in the Early Jurassic (about 180 m.y. ago) and continued for about 25 m.y. No plutonic rocks older than Jurassic have been recognized. Plutons of Jurassic age form an arcuate belt about 600 mi long which roughly parallels the Talkeetna geanticline and Matanuska geosyncline, major tectonic elements of south-central Alaska. Jurassic plutonic rocks are largely diorite and quartz diorite with minor granodiorite. Upper Cretaceous and lower Tertiary plutons (83–55 m.y.) occur locally within this belt, but in the southern Alaska Range these plutons characteristically form north-trending belts transverse to the earlier tectonic elements and locally extend out into what was probably a more stable area bordering the earlier tectonic features. Composition of these plutons ranges from diorite through granite, but granodiorite and quartz monzonite predominate. Isolated granitic stocks of this age also extend eastward into the central Alaska Range. The data suggest that this period of magma generation and emplacement may be separated into Late Cretaceous (70–85 m.y.) and early Tertiary (50–65 m.y.) plutonic episodes. Middle Tertiary plutons (34–41 m.y.) form a north-trending belt about 100 mi long in the central part of the southern Alaska Range. These rocks, characteristically granites and quartz monzonites, are flanked by more mafic lower Tertiary and Upper Cretaceous plutons. Small plutons of middle Tertiary age also are present locally in the central part of the Alaska Peninsula. A still younger plutonic episode (25–30 m.y.), perhaps a later phase of the middle Tertiary episode, is represented by small isolated granitic stocks. The plutonic rocks of the central and southern Alaska Range and Alaska Peninsula are more silicic with decreasing age.

Geology of the Anchorage area

Field studies by S. H. B. Clark have shown that bedrock of the Chugach Mountains in the area between Anchorage and Whittier (loc. 14) can be divided into the following two major units: (1) a weakly metamorphosed heterogeneous assemblage of clastic rocks, volcanic rocks (including pillow lavas), radiolarian chert, and sparse marble and serpentinite; and (2) a thick flysch sequence (Valdez? Group).

Fossils from a new locality in the flysch are similar to the Late Cretaceous (Maestrichtian) *Inocermus kusiroensis* according to D. L. Jones. This determination indicates that the flysch deposits of the Chugach Mountains in the Anchorage area which are thought to be deep-water marine deposits are, at least in part, coeval with the Matanuska Formation, which was deposited at shallow to moderate depths on the continental shelf. [67]

Rocks of the heterogeneous assemblage overlie the flysch and appear to be younger, but the possibility that they are older Cretaceous rocks in fault contact with the flysch has not been ruled out.

Metamorphic assemblages from northwest to southeast (probably with increasing depth) include quartz-calcite-

[67] Grantz, Arthur, 1964, Stratigraphic reconnaissance of the Matanuska Formation in the Matanuska Valley, Alaska: U.S. Geol. Survey Bull. 1181-I, 33 p.

laumonite-prehnite-albite near the front, quartz-albite-prehnite-pumpellyite-calcite-chlorite-epidote in most of the heterogeneous assemblage, and quartz-albite-chlorite-white mica-calcite-epidote in most of the flysch sequence. A glaucophane schist clast was found in a prehnite-pumpellyite(?) that contains conglomeratic volcanic sandstone from the heterogeneous unit. The only other known occurrence of glaucophane in the area is near Seldovia.

About 22 mi northeast of Anchorage an elongate, layered ultramafic body, described by A. W. Rose,[68] is in fault contact with the heterogeneous assemblage. Some of the rocks northwest of the ultramafic body are known to be older (Permian to Jurassic) than the flysch and heterogeneous assemblage. The ultramafic body may mark the boundary between two significantly different terranes—the flysch and heterogeneous assemblage of the Chugach Mountains to the southeast and the older rocks, which represent the basement upon which the Matanuska Formation was deposited, to the northwest.

Paleozoic rocks in the western Chugach Mountains

S. H. B. Clark discovered fusilinids, identified as Permian by R. C. Douglass, from samples of a marble outcrop a few hundred feet from the west contact of the Eklutna ultramafic body (loc. 15). This is the first pre-Triassic age that has been established in the western Chugach Mountains. R. C. Douglass reported that one fusilinid, *Cancellina*, a neoschwagerinid, is the first known neoschwagerinid in Alaska, and that this is only the third place in the Western Hemisphere where *Cancellina* has been recognized.

Plate tectonic theory and southern Alaska

Southern Alaska, where the Alaska orocline is expressed by arcuate mountain ranges, is the junction of the trends of the Aleutian arc and the Fairweather–Queen Charlotte continental-margin transform fault. Because island arcs and transform faults are key elements in plate tectonic theory, several southern Alaska geologists have begun viewing major features of the region in terms of the various models of plate tectonics.

Regional analysis of upper Mesozoic rocks in southern Alaska by D. L. Jones shows that three major belts can be recognized: (1) northern, (2) southern, and (3) southeastern. The northern belt formed at the continental margin; the southern belt is of deep oceanic origin and has been collapsed against the continent by sea-floor spreading. The southeastern belt, whose northwest terminus is in the eastern Alaska Range, lies across the other belts and truncates them. This juxtaposition is probably due to strike-slip faulting.

Detailed reconnaissance geologic mapping by D. H. Richter, N. A. Matson, Jr., and D. L. Jones in the eastern Alaska Range (loc. 16) suggests that a Permian volcanic island arc collapsed against the North American Continent probably in Late Permian or Early Triassic time. Since then this terrane has been multiply deformed as later oceanic plates impinged against the continental margin. The Denali fault, which follows the island arc–continent suture, is a dextral strike-slip structure formed during the late Miocene. The Totschunda fault, which diverges from the Denali fault in the eastern Alaska Range trending southeasterly toward the Fairweather fault, is another major dextral strike-slip structure that may have developed as recently as the middle Pleistocene. The average Holocene slip rate along the Totschunda fault and northwest segment of the Denali fault is about 2 to 3 cm/yr. The Denali fault southeast of the Denali-Totschunda junction appears inactive. Plate tectonic theory indicates that the Denali-Totschunda faults are part of a major transform system separating the North American and Pacific plates. Hence, continental southern Alaska between the Aleutian arc and the Denali fault has been decoupled from the North American plate and is now largely moving with the Pacific plate.

Geologic investigations by E. M. MacKevett, Jr., in the southern Wrangell Mountains (loc. 17) along with investigations of nearby regions by D. H. Richter and George Plafker are fundamental in the recent derivation of geotectonic concepts that are compatible with plate tectonics in part of southern Alaska. These concepts were mainly deduced by D. L. Jones. In essence they postulate that rocks of the Skolai Group (Lower Permian and possibly locally older) represent oceanic crust or island arc terrane that was impinged and partly subducted against the continent during the Late Permian or Early Triassic. Voluminous eruptions of continental flood basalts, the Nikolai Greenstone, derived from the upper mantle during the late Middle and (or) early Late Triassic, generated local depressions that were sites for the dominantly shallow marine sedimentation recorded in the southern Wrangell Mountains intermittently throughout the Late Triassic, Jurassic, and Cretaceous. The late Mesozoic geologic history of the region north of the Wrangells, on the basis of the investigations of Richter, is markedly different from that of the southern Wrangells, an indication that the two terranes became juxtaposed by rifting. Most late Mesozoic and subsequent igneous and structural activity in the southern Wrangells is inferentially related to sea-floor spreading.

Marine terraces and earthquakes

George Plafker and Meyer Rubin have completed a study of a sequence of uplifted marine terraces on Middleton Island in the Gulf of Alaska (loc. 18) that has provided new insight into the recurrence interval of major tectonic earthquakes and the uplift rate in the eastern Aleutian arc. Emergence of the island in distinct jumps, separated by intervals of stability or gradual submergence, is recorded by six gently sloping marine terraces separated by wave-cut cliffs or rises with average beach-angle elevations above present mean high water of about 4, 14, 23,

[68] Rose, A. W., 1966, Geology of chromite-bearing ultramafic rocks near Eklutna, Anchorage quadrangle, Alaska: Alaska Div. Mines and Minerals Geol. Rept. 18, 20 p.

30, 40, and 46 m. The lowest terrace is a marine surface that was uplifted 4 m suddenly during the 1964 Alaska earthquake as a result of relative seaward thrusting of the continental margin. Uplift of each of the five older terraces presumably was also accomplished in jumps of 7 to 11 m each during one or more major tectonic earthquakes. Twenty-four radiocarbon dates of peat and driftwood from the older terraces have provided close dating for four of them and a minimum age for the fifth one. These data suggest that sudden uplift has affected the Middleton Island area at intervals ranging from about 500 to 1,400 yr since the island initially emerged from the sea about 4,300 yr ago. The average uplift rate is about 1 cm/yr during the 4,300-yr period but only about half that amount during the last 1,400 yr. Thus, if the deformation rate is reasonably constant, Middleton Island is overdue for another increment of uplift comparable to that which occurred during the 1964 Alaska earthquake in order to maintain the long-term uplift rate.

Talus cone growth

A significant increase in the size of a talus cone near the terminus of the Eklutna Glaciation (loc. 19) during the 7 yr since the Alaska earthquake was documented by comparison of photographs taken by H. L. Foster and T. N. V. Karlstrom shortly after avalanche activity began in 1964 with photographs taken by S. H. B. Clark and S. R. Bartsch in July 1970. The growth of the talus cone has been the result of avalanche activity triggered by the earthquake and continuing intermittent rock falls. Calculations from approximate measurements indicate that about a million cubic yards of rock have been added to a preexisting stabilized cone after the 1964 photographs were taken. Avalanche activity in other places in the same area was also triggered by the earthquake, but the activity has continued at a rate sufficient to produce a significant change in the talus in only this one place. Observations on the ridge above the talus cone suggest that a combination of the oversteepened face and the strongly fractured, homogeneous, massive nature of the bedrock in an area of frequent freezing and thawing are sufficient to account for the activity.

Igneous rocks of the Wrangell Mountains

Studies in the southern Wrangell Mountains (loc. 20) by E. M. MacKevett, Jr., have clarified the genesis and relationships of most igneous rocks of the area. For example, the oldest known rocks in the region, Lower Permian and possibly older submarine basaltic lavas and their metamorphosed counterparts and probably some gabbros, are interpreted to represent oceanic crust or island arc terrane. The younger intrusives are largely shallow-seated phases related to the early stages (late Tertiary) of Wrangell Lava volcanism that ranges from Miocene to Holocene. These intrusives form crudely linear belts along the southern flank of the range mainly south of the lava fields. Jurassic granodiorite and related rocks, which are locally distributed in the southwestern Wrangells, are inferentially related to late Mesozoic orogenic processes that affected the region.

The Jurassic granodiorite plutons may warrant more detailed exploration for mineral deposits. They are generally more altered than the Tertiary plutons, and some of them contain low-grade zones of copper minerals similar to porphyry copper deposits and small sulfosalt-bearing quartz veins that are rich in silver. It is conceivable that thorough exploration might disclose deposits of either type that are economically attractive.

SOUTHEASTERN ALASKA

Ultramafic bodies and moon rocks

The Union Bay (loc. 21) and Eklutna (loc. 15) ultramafic bodies both appear to have a complex structural history, according to A. L. Clark. Petrofabric analysis of dunite samples from the core of the Union Bay ultramafic body in southeastern Alaska indicates that the core has been deformed by shear or flow folding. The Eklutna ultramafic body in the Chugach Mountains is locally sheared internally and in places can be observed in fault contact with surrounding country rock.

The techniques and criteria used in the study of these Alaskan ultramafic rocks were applied in petrofabric analysis of a lunar sample obtained from the Apollo 12 lunar mission. The results indicate that flow foliation is present in lunar sample 12052.

Geochemical studies undertaken in conjunction with the ultramafic sampling show trace amounts of platinum and palladium in both the Union Bay and Eklutna ultramafic bodies. The platinum-group anomalies in the Union Bay samples are associated with chromite and magnetite-rich zones; in the Eklutna ultramafic body, however, the platinum-group anomalies are associated with high copper content in pyroxenite, peridotite, and wehrlite.

Juxtaposed geologic terranes of Gravina Island

Geologic mapping of Gravina Island (loc. 22), completed in 1970 by H. C. Berg, indicates that the island consists of two dissimilar geologic terranes possibly brought together by large-scale faulting.

The evidence for the juxtaposition is mainly stratigraphic. Southwestern Gravina Island is underlain by rocks ranging in age from Silurian (or older) to Late Jurassic, whereas northeastern Gravina Island is made up mostly of Middle(?) Jurassic andesitic rocks whose basement has not been observed. These assemblages of partly coeval rocks are separated by a deep, alluvium-filled valley that trends northwestward for the length of the island. Rocks exposed near the valley are intensely sheared. Thus the available evidence indicates that the valley marks the trace of a major fault across which the different rock assemblages have been juxtaposed.

The assemblages now recognized on Gravina Island probably can be recognized in many places throughout the 300-mi-long Wrangell-Revillagigedo belt of southeastern Alaska. If, as seems likely, they are in fault contact elsewhere in the belt, then this juxtaposition probably has regional tectonic significance.

Oldest metamorphic rocks in southeastern Alaska

A. L. Clark's detailed mapping and sampling on the southern end of Dall Island and on Sukkwan and Long Islands (loc. 23) reveal that several ultramafic bodies of early Paleozoic age intrude a high-grade metamorphic complex. Because these ultramafic rocks are unmetamorphosed, the metamorphic complex must be very early Paleozoic in age. These would be the oldest rocks in southeastern Alaska.

Paleomagnetic studies of samples of the ultramafics by C. S. Grommé and E. A. Mankinen show that magnetic fields for the Dall, Long, and Sukkwan Island rocks are similar to the magnetic fields for samples previously studied from the Harmony Islands.

Recent faulting near Coronation Island

No direct measure of the recency of movement is available for the southern 200 mi of the Chatham Strait fault because it is not exposed on land (loc. 24). Geologic studies of displaced terrane east and west of the fault suggest as much as 120 mi right-lateral separation and a mile or two dip separation. The fault is one of the major features of the North American part of the Pacific Ocean rim.

Marine seismic profiling near the southern end of the fault, undertaken in 1970 by A. T. Ovenshine and H. C. Berg, reveals north-trending faults and folds in weakly consolidated sediment of possible postglacial age. These structures are west of Coronation Island and east of the Chatham Strait fault; they parallel the trace of the Chatham Strait fault and presumably are related to it.

PUERTO RICO

Eocene unit correlated with deep-sea Horizon A

D. H. McIntyre and J. M. Aaron believe that the Guacio Member of the Río Culebrinas Formation may be an uplifted equivalent of the deep-sea acoustical reflector Horizon A. Ewing, Windisch, and Ewing[69] correlate Horizon A with a lower middle Eocene chert horizon sampled during the Joides deep-sea drilling program. On Puerto Rico the Guacio Member is a widespread unit of siliceous and calcareous mudstone that is unique within a thick lower Tertiary sequence of volcanic rocks deposited in a deep-water environment. A lower middle Eocene determination by E. A. Pessagno, Jr. (University of Texas), for rocks a short distance stratigraphically below the Guacio Member, together with numerous middle Eocene determinations by K. N. Sachs, Jr., for samples collected higher in the sequence, suggest that the Puerto Rico unit is indeed close in age equivalence to the chert horizon in the Joides cores, Horizon A.

Miocene stratigraphy

Petrographic studies by J. M. Aaron of thin sections from the Isla de Mona Dolomite disclosed that a number of largely unaltered planktonic Foraminifera were present in some samples. The foraminifers were examined by E. A. Pessagno, Jr. (University of Texas), who believes that they are representative of the middle Middle Miocene, zones N 12 to the lower part of N 13 of Blow. This find provides the first definitive age determination on this rock unit, which occurs on Isla de Mona, a small island from which phosphorite once was extracted. Isla de Mona lies about halfway between Puerto Rico and Hispaniola.

Field studies in southern Puerto Rico by W. H. Monroe show that between Guayanilla and Guánica the so-called upper member of the Ponce Limestone of Oligocene and Miocene age progressively overlaps the lower member and the underlying clastic rocks of the Juana Díaz Formation of Oligocene age. In southwestern Puerto Rico near Parguera the unit rests directly on Cretaceous rocks.

Porphyry copper studies

Preliminary petrographic studies by D. P. Cox of hornblende quartz diorite porphyry stocks closely associated with porphyry-copper-type mineralization indicate that propylitic alteration is most widespread in and around the deposits. Chloritization of hornblende with release of magnetite and titanium minerals is common. Albitization of plagioclase is widespread, and in some deposits the rocks are completely replaced by albite, chlorite, magnetite, and sulfides. Sericitic and argillic alteration are apparently structurally controlled and do not occur in distinct zones. K-feldspar–biotite alteration is widespread in some deposits and confined to the interior zones of others. Anhydrite and gypsum occur in several of the deposits, and late stage zeolite-calcite veins are widespread.

An Eocene age for the stocks and related porphyries suggested in 1968 by P. H. Mattson[70] has been confirmed by R. F. Marvin. K-Ar determinations show late Eocene age for hornblende in unmineralized porphyry near the ore deposits and for sericite in mineralized porphyry.

[69] Ewing, J., Windisch, C., and Ewing, M., 1970, Correlation of Horizon A with Joides bore-hole results: Jour. Geophys. Research, v. 75, p. 5645–5653.

[70] Mattson, P. H., 1968, Geologic map of the Adjuntas quadrangle: U.S. Geol. Survey Misc. Geol. Inv. Map I-519, 1:20,000.

Stratigraphic geochemistry

According to R. P. Briggs, new atomic-absorption and spectrographic analyses of 600 volcanic and plutonic rocks confirm the earlier suggestion by Briggs, Mattson, and Glover[71] that the middle Cretaceous (Albian-Santonian) Robles–Río Orocovis sequence contains more copper (commonly in the range 150–250 ppm) than do older (commonly 80 ppm or less) and younger (commonly 50 ppm or less) Cretaceous and lower Tertiary volcanic sequences of the central volcanic-plutonic subprovince. These analyses performed by the new Natural Resources Laboratory of the Puerto Rico Department of Public Works also show that the Robles–Río Orocovis sequence contains more potassium and barium than do underlying and overlying sequences.

GEOLOGIC MAPS

Much of the work of the U.S. Geological Survey consists of mapping the geology of specific areas, mostly for publication as quadrangle maps at scales of 1:24,000, 1:62,500, and 1:250,000. Mapping the geology of the United States is a mandate of the Organic Act establishing the Geological Survey; the completion of geologic maps for the country at scales that will fulfill foreseeable needs and uses is a long-range goal.

The systematic description and mapping of rock units to show local and regional relations serve a major scientific objective, but most maps also serve more specific purposes as well. Some of the studies are for the purpose of extending geologic knowledge in areas of known economic interest; some are to gain detailed knowledge for engineering planning or construction. Still other mapping studies are carried on with the primary objective of providing solutions to problems in paleontology, sedimentary petrology, or a wide variety of other specialized topics.

LARGE-SCALE GEOLOGIC MAPS

Large-scale geologic mapping, principally at scales of 1:24,000 and 1:62,500, constitutes almost four-fifths of the geologic mapping program of the U.S. Geological Survey. Such large-scale maps are available for nearly one quarter of the conterminous United States. Approximately half these maps have been produced by the Geological Survey; most of the remaining maps have been produced by various State organizations and educational institutions.

The Geological Survey is carrying out large-scale geologic mapping projects in many parts of the country, with extensive cooperative programs underway in Connecticut, Kentucky, Massachusetts, and Puerto Rico. Other areas where mapping is underway include the Pacific Northwest, California, Delaware, Maryland, Michigan, Nevada, Ohio, Pennsylvania, Tennessee, Virginia, and the Rocky Mountain States.

Large-scale geologic maps play a vital role in furthering scientific knowledge of the earth and also have many applied uses. Maps of mineralized areas not only help determine the scientific principles that govern formation and distribution of ore deposits but also are used as the basis for exploration for economic mineral deposits and for the preparation of reserve and resource estimates.

Many geologic maps are prepared in search for a better understanding of the processes and mechanisms that affect the earth's crust. Uses of these maps are growing in number and importance in the field of planning for more logical land use and for such large-scale engineering works as damsites, highway alinements, and subway routes. Actual construction is aided through location of vital construction materials and by providing the basis for site-preparation cost estimates. Another extremely valuable use of geologic maps is as an aid to avoiding hazards such as landslides, swelling clays, and those areas possibly subject to extensive damage during floods and earthquakes.

INTERMEDIATE-SCALE GEOLOGIC MAPS

Geologic mapping at a scale of 1:250,000 makes up an increasingly important part of the U.S. Geological Survey's geologic investigations program. The 1:250,000 and smaller scale geologic maps generally are compiled from available large-scale geologic maps and supplemented by reconnaissance geologic mapping at intermediate scales. Mapping at 1:250,000 has now expanded to a point where it constitutes more than one-fifth of the geologic mapping program of the Geological Survey. Many State geological surveys also have 1:250,000-scale geologic mapping programs which are underway or completed. These efforts by the Federal and State surveys as a nationwide program promise to provide geologic-map coverage of two-thirds of the United States by 1985; at the present time nearly 40 percent is covered. Figures 2 and 3 show the areas of the United States for which 1:250,000-scale maps have been published.

The Geological Survey is participating in mapping programs that will provide 1:250,000-scale geologic maps of most or all of Alaska, Colorado, and Nebraska within a few years. Single-sheet 1° by 2° geologic maps have been started in parts of Washington, Oregon, Idaho, Montana, Wyoming, Utah, Arizona, New Mexico, North Carolina, South Carolina, and Virginia.

Intermediate-scale geologic maps have a variety of uses. They help define areas where the need for larger scale maps is most critical, and they direct attention to broad geologic problems involving large segments of the earth's crust. They have proved ideal for geologic analysis of major tectonic and stratigraphic problems, for analysis of mineral provinces, and

[71] Briggs, R. P., Mattson, P. H., and Glover, Lynn, 3d, 1965, Copper impoverishment during successive igneous events in Puerto Rico—A clue to the origin of copper ore [abs.]: Congreso Latinoamericano de Química, 9th, San Juan, Puerto Rico, 1965, Resúmenes de los Trabajos, p. 31–32.

for relating broad geophysical anomalies to surface geology. A significant use for geologic maps at intermediate scales, although still largely potential at this time, is as the basis for a systematic inventory of land uses and resources throughout the Nation.

MAPS OF LARGE REGIONS

Several maps of all or large parts of the United States currently are in preparation. These maps, at scales ranging from 1:2,500,000 to 1:10,000,000, present reviews of various geologic features of the Nation in forms that show overall characteristics of the features in detail commensurate with the scales. Most are intended both as wall maps for contemplative reviewing and as working maps for further specific studies.

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

Most of the conterminous United States has been plotted in preliminary form. This compilation is undergoing critical review by regional specialists and resolution of differences by the senior compiler. Simplification of the map explanation over that used on the existing map published almost 40 yr ago is possible because of (1) extensive new data, (2) improved stratigraphic correlations, and (3) radiometric dating of volcanic, plutonic, and Precambrian rocks. The map will show the vast increase in knowledge gained during the last four decades.

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

A contribution to the Metallogenic Map of the World sponsored by the Commission for the Geologic Map of the World of the International Geological Congress and the International Union of Geological Sciences. Prepared in cooperation with the Geological Survey of Canada, the Institute of Geology of the University of Mexico, the Geological Survey of Greenland, and the Instituto Centro Americano de Investigacion y Technologia Industrial. This map will show major known deposits of metal-bearing and nonmetallic minerals and their geologic-tectonic settings. A coproduct of the map compilation will be computer storage of data on deposits to facilitate rapid retrieval.

Metamorphic map of the Appalachians, scale 1:2,500,000, B. A. Morgan, compiler.

A contribution to a Map of Metamorphic Belts of the World sponsored by the Commission for the Geological Map of the World of the International Geological Congress and the International Union of Geological Sciences. The map for the Appalachians within the United States shows biotite, garnet, staurolite, kyanite, andalusite, and sillimanite in pelitic schists, areas of greenschist and amphibolite mineral facies, and facies series characterized by andalusite-sillimanite and by kyanite-sillimanite transitions.

Geologic map of Oregon, scale 1:500,000, G. W. Walker, compiler.

Compilation of the eastern part of the State is nearing completion; a map of the western part of the State was previously published. [72] The present compilation, showing more than 50 geologic map units, is based partly on available published and unpublished maps and partly on extensive new reconnaissance and photogeologic mapping. An inset tectonic map, scale 1:2,000,000, shows distribution of fold axes and major surface faults, and the position of postulated calderas and deeply buried faults.

Analysis of the Pennsylvanian System, by E. D. McKee and others.

The analysis will include various maps at scales of 1:5,000,000 and 1:10,000,000 depicting structural elements during successive divisions of the Pennsylvanian System, types and distribution of rocks deposited during each division, and specialized information such as probable source areas for sediments, coal, and evaporites.

Analysis of the Mississippian System, by L. C. Craig and others.

The analysis will include various maps at scales of 1:5,000,000 and 1:10,000,000 showing the standard information on structural elements and rock distribution during Mississippian time, and also special information maps. Interpretations indicate that at maximum submergence, during Osage time, approximately 80 percent of the conterminous United States was covered by marine waters, and that at minimum submergence, at the end of the Mississippian, 33 percent was covered.

WATER RESOURCES

The U.S. Geological Survey conducts investigations, surveys, and research on the occurrence, quality, quantity, distribution, utilization, movement, and availability of surface and underground waters that comprise the Nation's water resources. This work includes investigations of floods and droughts, their magnitude, frequency, and relation to climatic and physiographic factors; the evaluation of available waters in river basins and ground-water provinces, including water requirements for industrial, domestic, and agricultural purposes; the determination of the chemical and physical quality of water resources and the relation of water quality and suspended sediment load to various parts of the hydrologic cycle; and special hydrologic studies of the interrelations between climate, topography, vegetation, soils, and urbanization and the water supply. One of the Survey's most important activities is the systematic collection, analysis, and interpretation of data for evaluating the Nation's water resources. These data are computer processed for storage and retrieval and for dissemination of water information.

[72] Wells, F. G., and Peck, D. L., 1961, Geologic map of Oregon west of the 121st meridian: U.S. Geol. Survey Misc. Geol. Inv. Map I-325, 1:500,000.

Figure 2.—Index map of the conterminous United States, showing 1:250,000-scale geologic maps published as of June 30, 1971.

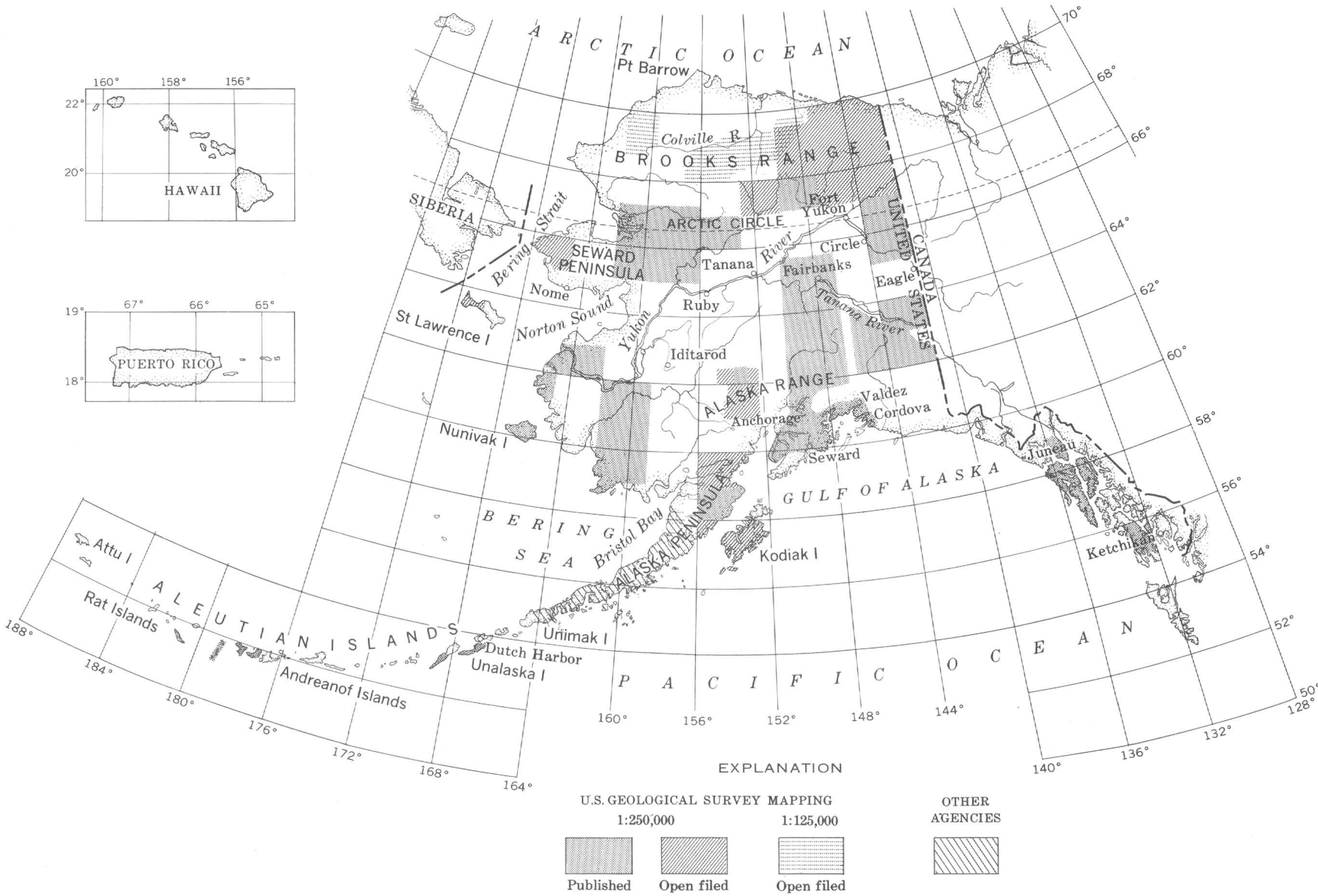


Figure 3.—Index map of Alaska, Hawaii, and Puerto Rico, showing geologic maps published or open filed as of June 30, 1971.

The Geological Survey has the responsibility for coordination of national network and special water-data acquisition activities, and the maintenance of a central catalog of water information for use by Federal agencies and other interested parties.

Research is conducted to improve the scientific basis of investigations and techniques in hydraulics, hydrology, instrumentation, and in the chemical and physical properties of water. The research may be grouped in the following categories: properties of water; the hydrologic cycle (drainage, runoff, and watersheds; evaporation, meteorology, and precipitation; flow, hydraulics, and streams; ground water; soil water; lakes and reservoirs; water and plants; erosion, sedimentation, and sediments; and estuarine problems); saline water; water use; agriculture, irrigation, and pesticides; water management; water pollution effects, water pollution sources and water quality; waste water disposal; planning and water-resources development; water law; environment; corrosion; data handling methods; and digital computer techniques, systems, and models.

A significant part of the Geological Survey's water-resources activities is the providing of other Federal agencies with scientific and technical assistance in appropriate fields where knowledge gained from Geological Survey research projects may be helpful. When the Survey's interests are related to the interests of other agencies, the Survey's assistance contributes to the efficiency of their programs and encourages the maintenance of high standards of technical accomplishment.

The Geological Survey develops ground- and surface-water technology and the technologies necessary for dealing with (1) the chemical, physical, and biological properties of water; and (2) the interrelation of these water-quality properties and characteristics with hydrologic, geologic, geochemical, biological, and ecological environments.

Surface-water studies during fiscal year 1971 included collection and analysis of data on streamflow, floods, and quality of water. Data on streamflow were collected at about 11,200 stream-gaging stations, 7,165 of which are equipped with digital recorders, and at 1,442 lake- and reservoir-level stations. Approximately 900 quadrangle maps and 60 pamphlets which have information about flood-prone areas were published in 1971. Studies of quality of surface water were expanded, and approximately 4,350 water-quality stations in the United States and its possessions were involved in these studies. Parameters measured include those of selected major cations and anions, specific conductance or dissolved solids, pH, and other selected quality characteristics. Other parameters, measured as needed, included trace elements, phosphorous and nitrogen compounds, detergents, pesticides, radioactivity, phenols, biochemical oxygen demand, and coliform bacteria. Streamflow records were collected at most of the water-quality stations, and water temperature was recorded continuously or at the time of sampling at about 3,660 water-quality stations. Sediment data were obtained at 890 locations.

In 1971 almost 500 U.S. Geological Survey scientists reported on areal water-resources studies and research on hydrologic principles, processes, and techniques. Of current water-resources studies about 150 studies are directly related to urban-hydrology problems and about 180 indirectly related. Comprehensive river-basin planning studies are in progress for several major regions of the United States. Ground-water studies of varying degrees of intensity have been made or are currently in progress for about two-thirds of the Nation. Daily measurements of ground-water levels were made in 2,285 wells, and periodic measurements were made in 26,348 wells. Studies of saline-water aquifers, particularly as a medium for disposal of waste products, are receiving increasing attention as are hydrologic principles governing the occurrence of brackish water in estuaries. Studies of land subsidence were extended into additional areas where problems are developing, and the possibilities of accomplishing ground-water recharge to solve the subsidence and ground-water depletion problems were examined.

The use of computers for research studies of hydrologic systems and for storing data continued to increase in fiscal year 1971. Records of about 220,000 station years of streamflow data and information on some 35,000 wells and 4,000 water-quality stations are available. The streamflow records have been placed on 30 magnetic tapes and the quality-of-water records on 7 tapes. Digital computer techniques are used to some extent in almost all of the research projects, and new techniques are being developed.

The water-resources activities selected by the U.S. Geological Survey (U.S. Geol. Survey, r0632, p. A56–A57) as its contribution to the International Hydrological Decade (IHD) were continued in 1971. A résumé of certain activities in the IHD program for 1971 (p. A93–A94) concludes the water-resources section of this chapter, and more detailed reports on some of the activities appear, where appropriate, in other sections.

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

Investigations describing the occurrence of water as a natural resource in the environment are given in the following section for the four regions of the United States (fig. 4) used by the Geological Survey for administering the program.

ATLANTIC COAST REGION

Water problems in the Atlantic coast region are apparently little different in 1971 than they were in 1969 or any other recent "average" year, except for the damaging drought in

Figure 4.–Index map of the conterminous United States, showing areal subdivisions used in discussion of water resources.

southern Florida. Actually, however, some hydrologic problems are new in the sense that they are only now being recognized as problems or as potential problems. Some have to do with water-carried "exotic" materials released from ordinary household and industrial substances. Organic chemists are vigorously attacking these problems with new or more refined analytical methods. Rapid, portable, efficient, accurate, automated, and telemetric are all words descriptive of new water-quality monitoring techniques. Other problems, though not new, are being studied from new angles. Chemists and aquatic biologists are sampling and analyzing biota from streams, lakes, and estuaries to monitor effects of acid mine drainage, thermal pollution, and back pumping of storm-sewer effluent. The relations of physical, chemical, and biological properties of drainage basins to the same general properties of the basins' impoundments are being studied in order to establish general guidelines for new reservoir design and for operation of existing impoundments. The movement of water in tide-affected sounds, as related to movement of pollutants, is being analyzed by digital model. Maximum safe draft from reservoirs is being determined, and some flow characteristics of streams are being adequately defined by use of regionalization techniques. Flow characteristics observed by continuous records (mean annual flow, mean monthly flow, and so forth) may be estimated from known basin characteristics. Other studies involve the costs of developing ground water as an alternative or supplemental source of water supply in areas historically supplied by surface water and the interrelations of the two sources of supply along with their contributions, each to the other, with changing climatic factors.

NEW ENGLAND

Ground-water resources of the Barre-Montpelier area, Vermont

In phase 1 of a test program in the Barre-Montpelier area, Vermont, 5,665 feet of seismic-refraction profiling was completed along five valley cross sections, according to A. L. Hodges, Jr. The profiles indicated that the thickness of alluvium ranged from 30 to 140 feet. Later drilling proved the seismic interpretation to be accurate within 5 feet.

Phase 2 included wash-bore test drilling and installation of 1¼-inch observation wells. All holes were drilled to refusal of deeper penetration. Later drilling of large-diameter test wells, however, indicated that the refusal had been above the base of the aquifer.

Phase 3, currently in progress, provides for the construction of test wells and test pumping. Preliminary results of a pumping test of an 8-inch-diameter test well completed in 80 feet of water-bearing gravel in East Montpelier indicate a transmissivity of 4.0×10^4 cu ft per day per ft, or approximately 300,000 gpd per ft. A second test well is being installed in Northfield. Thus far, more than 90 feet of water-bearing sand and gravel has been penetrated.

Water resources of the Deerfield-Hoosic River basins, northwestern Massachusetts

Analysis of base-flow measurements in the Hoosic River basin by L. G. Toler, F. B. Gay, and B. P. Hansen indicated that annual minimum 7-day mean flows range from 0.008 to 0.13 cfs per sq mi at a 10-yr recurrence interval. Variations are attributed to differences in rainfall and loss of streamflow to the unconsolidated deposits.

Dissolved solids in stream water range from about 30 to 300 mg/l. Concentrations are lower in streams draining noncarbonate metamorphic rocks or glacial till. Streams draining carbonate rocks are high in dissolved-solids content and hardness. Municipal and industrial waste in the Hoosic River causes highest dissolved solids, increases pH (range 6.6–9.6), and decreases dissolved oxygen to less than 4.0 mg/l during many days in summer.

Hydrology and water resources of the Neponset-Weymouth River basins, Massachusetts

R. A. Brackley, W. B. Fleck, and W. R. Meyer reported that average surface-water flow out of the study area on the southern suburban fringe of Boston is about 200 cfs. Estimated 7-day low flows of the tributaries at the 10-yr recurrence interval range from 0 to 0.27 cfs per sq mi because of diversions, differences in geology, and ground water underflow to adjacent areas. Apparently ground water flows from the Taunton River basin northward into the East Branch Neponset River basin. The estimated 7-day low flows at the 10-yr recurrence interval for some of the southern tributaries in the East Branch Neponset River basin are about 0.2 cfs per sq mi, whereas for the adjacent tributaries in the Taunton River basin these flows are only about 0.05 cfs per sq mi, according to J. R. Williams. Sparse water-table data in this vicinity also suggest a northward movement of ground water from the Taunton River basin. Damaging floods are minimized because of storage provided by the flood plains and lakes, low stream gradients, and the relatively undeveloped flood plains. During the flood of March 1968, the peak of the Neponset River at Norwood was 1,140 cfs, and at a downstream site in Hyde Park the peak was only 1,550 cfs, even though the Hyde Park drainage area is about three times larger than the Norwood drainage area.

Stratified drift deposits as thick as 150 feet crop out in 52 percent of the area. Wells in this material may yield 300 gpm or more.

Generally, ground water is soft (60 mg/l or less of calcium carbonate) and mildly acid. In many areas, however, particularly near roadways, hardness is increasing. In places these increases averaged 10 mg/l per yr during the mid-1960's.

Water resources, Charles River basin, eastern Massachusetts

The flow of typical tributaries in the Charles River basin, after rainless periods of 5 days or more, shows a range from around 1 to 0.05 cfs per sq mi of drainage area, according to E. H. Walker, W. W. Caswell, and S. W. Wandle. Low flows correlate with geology; higher flows are associated with basins of glacial sand and gravel.

Dissolved-solids content of surface waters ranges from about 50 mg/l in uncontaminated streams to more than 300 mg/l in contaminated streams and averages around 90 mg/l in the Charles River near its mouth. Historic data indicate that the dissolved-solids content of the Charles River increased little until the late 1940's; since then the increase has been more rapid. Most of the increase has been caused by additional chloride, and most of the chloride probably originates as road salt, though some comes from sewage.

Water resources of the coastal basins of southeastern Massachusetts

Reconnaissance geologic mapping and analysis of well data by J. R. Williams and G. D. Tasker indicated that the principal aquifers in the Hingham to Kingston area are localized in preglacial valleys cut in bedrock. The permeable materials consist of deltaic, ice-contact, and outwash deposits. Sand and gravel aquifers commonly lie beneath glacial till or glaciolacustrine deposits. The aquifers in the Plymouth-Wareham area are among the most extensive in the State and are commonly more than 100 feet thick; they consist of gravelly end moraines and extensive outwash plains that border the moraines. Ground-water discharge from these aquifers provides most of the streamflow, and overland runoff is minor. The principal ground-water-quality problems are salt-water intrusion along the shore and in estuaries and salt contamination of some wells near heavily salted highways. Iron, manganese, and color are common problems in both surface water and ground water. Studies indicated that the specific conductance of the surface water varied directly with population density.

Aquifer in the Quinnipiac River valley, Connecticut

In a study of auger samples from the main valley of the Quinnipiac River, G. R. Tarver, D. L. Mazzaferro, and M. P. Thomas found the materials in the samples to be primarily sand and silt. Saturated thicknesses exceed 130 feet in parts of the valley from Meriden south to New Haven Harbor; several wells yield more than 1 mgd here. Unconsolidated materials in the smaller valleys are generally coarser, more poorly sorted, and thinner than those in the main valley.

Evaluation of selected stratified-drift aquifers in southeastern Connecticut

R. L. Melvin completed test augering and sampling of three stratified-drift areas in southeastern Connecticut previously delineated in a reconnaissance. Preliminary evaluation of the data indicated that the most promising area is in the Shunock and Pawcatuck River valleys, where thick permeable sand and gravel deposits have an excellent potential for development of large quantities of water. The ground-water potential is less in the two remaining areas of Four Mile River valley in East Lyme and at Lakes Pond Brook valley in Waterford, as saturated deposits of stratified drift are either thin or predominantly fine grained.

Stratified-drift aquifers, Blackstone River area, Rhode Island

Glacial deposits consisting chiefly of stratified sand and gravel constitute the principal aquifer in the Blackstone River area of northern Rhode Island. These deposits partly fill a narrow preglacial valley incised into comparatively impermeable bedrock. The aquifer ranges in width from 500 to 2,500 feet and, locally, is as thick as 150 feet. Wells tapping the aquifer derive most of their water from infiltration induced from the Blackstone River.

Computations by H. E. Johnston and D. C. Dickerman indicated that more than 95 percent of the average daily discharge of 0.8 mgd from a public-supply well owned by the town of Cumberland is from induced infiltration. The well is 195 feet from the river in a strip of aquifer about 1,000 feet wide, which has a maximum saturated thickness of about 70 feet. Measurements of an array of 19 observation wells near the Cumberland well showed that the area of the cone of pumping beneath the riverbed was 4.5 acres. Drawdown of the water table below the river level in this area averages 3.5 feet. From these data, the infiltration rate of the riverbed was computed to be 0.05 mgd per acre per ft of head loss. River temperature at the time of measurement was 4°C (39°F). The affected reach of river averages 155 feet in width and has a maximum water depth of about 10 feet. Streambed sediments are composed of coarse sand and gravel except for small patches of silty muck close to each bank.

NEW YORK

Hydrogeology of southern Nassau County, Long Island

H. F. H. Ku, John Vecchioli, and L. A. Cerrillo reported that within the Magothy aquifer the basal zone along a proposed barrier-well injection line in southern Nassau County is the most suitable zone for recharge. Except for the basal gravelly zone, the Magothy aquifer lacks laterally continuous clay or sand units in this area. In addition, most public-supply and industrial wells just north of the proposed injection alinement draw water from the lower half of the Magothy aquifer. The top and the bottom of the aquifer are capped by extensive clay beds that are hydraulically confining.

PENNSYLVANIA

Natural gas in water wells of Lackawanna County

Many water wells in the Catskill Formation on the Allegheny Plateau of northeastern Pennsylvania are reported to contain gases, some of which are highly inflammable and present a potential fire or explosion hazard unless properly vented. An analysis, by H. E. Koester and J. R. Hollowell, of the gas collected at the head of a flowing water well is reported, in percentage, as follows: methane 67.7, nitrogen 31.6, argon 0.4, helium 0.25, and traces of propane, hydrogen, and carbon dioxide. Much of the water contains hydrogen sulfide, ranging from traces to 5 mg/l.

One possible explanation for this phenomenon is the decomposition of organic effluents from peat bogs that enter the formation along fractures. The effluent is charged with carbonic and humic acids, and in carbonate-poor areas the organic materials decompose to form methane and hydrogen sulfide. An alternate source for the gas could be leakage from unknown natural traps.

Water resources of the Wissahickon Formation in southeastern York County

A study by O. B. Lloyd, Jr., and D. J. Growitz (p. D178–D181) indicated that ground water contributes about 75 percent of the total runoff from the Wissahickon Formation in southeastern York County. Base flow from a 133-sq-mi drainage basin averaged about 70 mgd from December 1, 1968, to November 30, 1970.

Wells in the Wissahickon Formation have a median specific capacity of 1 gpm per ft of drawdown. Test-drilling data indicate that better-than-average yields can probably be obtained from wells located on fracture traces that have tonal and topographic expression on aerial photographs. Water from wells is generally low in dissolved-solids content (less than 150 mg/l), soft (less than 60 mg/l total hardness), and acidic (pH between 5 and 7). Pollution is a local problem; about 25 percent of the ground-water analyses show nitrate concentrations that exceed 45 mg/l.

MARYLAND, DELAWARE, AND VIRGINIA

Two exploratory test wells drilled on the Delmarva Peninsula

Drill cuttings, cores, geophysical logs, and water samples were obtained by I. H. Kantrowitz from two test wells drilled on the Delmarva Peninsula. One well, near Chestertown, Md., was drilled to a depth of 2,009 feet and penetrated 56 feet of crystalline basement rocks. Fresh ground water (less than 1,000 mg/l dissolved solids) reaches a depth of about 1,180 feet. The principal undeveloped fresh-water aquifer occurs from 468 to 504 feet depth in nonmarine Cretaceous sedimentary rocks. A second well, near Greenwood, Del., was drilled to a depth of 1,506 feet; fresh water reaches a depth of about 630 feet. The Piney Point Formation (Eocene), an important aquifer in the central part of the peninsula, occurs from 562 to 813 feet. In the Greenwood area, the test site marks the approximate downdip limit of the Piney Point Formation as a fresh-water aquifer.

WEST VIRGINIA

Cavernous drains beneath anticlinal ridges in West Virginia

Data collected by W. A. Hobba, Jr., in the Potomac River basin of West Virginia indicate the presence of highly permeable "linear" cavernous zones beneath anticlinal ridges formed in Oriskany Sandstone and underlain by carbonate rocks of Devonian and Silurian ages. These zones parallel the anticlinal axes and have apparently developed along the intersections of major fracture planes and bedding planes. The zones are effective ground-water drains. Data supporting these conclusions include: (1) water levels in deep wells tapping the crests of ridges are at the levels of major streams bisecting the ridges; (2) moderately large to very large springs discharge from fractures or bedding planes at stream gaps near or beneath stream level, or at the nose of plunging anticlines near the contact of the Oriskany Sandstone with the overlying shale; and (3) published information on caverns in West Virginia and recent field investigations indicate that caverns are most often found in the carbonate rocks at or near the crests of anticlines. Fracturing at points of sharp folding in conjunction with bedding-plane separation caused by unloading along the fold axes has apparently caused increased permeability and solution by ground water.

NORTH CAROLINA

Study of surface-water data program in North Carolina

A study of the surface-water data program in North Carolina included examination and analysis of all available data for unregulated stations to determine whether statistical streamflow characteristics could be defined by regionalization. Using multiple-regression techniques, streamflow characteristics were related to basin and climatic variables. The accuracy goals for streamflow characteristics defined by regression techniques were those equivalent to 25 yr of record for streams with drainage area greater than 500 sq mi and equivalent to 10 yr of record for streams draining less than 500 sq mi. G. C. Goddard, Jr., reported that accuracy goals were met for 6 of 52 streamflow characteristics studied. The study indicated that the standard error of estimate was related to the size of the drainage area. The standard errors, in percentage, in the following table show the effect of size on accuracy of regression equations:

Streamflow statistic	Drainage area (sq mi)			
	4.6 to 59.5	59.6 to 124	125 to 347	348 to 4,810
Annual peak flow, 2-year recurrence interval.	41	39	34	19
7-day annual minimum flow, 10-year recurrence interval.	410	350	56	80

The anomalously high standard error in the last column of the last line may be erroneous as data were based on a small sample.

Regional draft-storage curves developed for North Carolina

As demands for surface water increase, water users and potential users are requesting data concerning the maximum safe draft from a reservoir. These users wish to provide storage to allow draft from a stream in excess of low flow. To make these data readily available, W. M. McMaster (r0768) and E. F. Hubbard, Jr., have developed regionalized draft-storage curves for North Carolina streams. These relations are indexed to the 7-day, 2-yr low flow of the stream. A user can determine the storage required for any draft rate by entering the curves with an estimate of the 7-day, 2-yr low flow at the site of withdrawal. For example, the curves predict that a reservoir having a 10,000-acre-ft capacity on a stream with a 7-day, 2-yr low flow of 20 cfs could produce a draft of 52 cfs with only a 5-percent chance of deficiency. Accuracy of draft figures obtained from these curves varies, but the estimate of 52 cfs is accurate within a standard error of 10 cfs.

SOUTH CAROLINA

Water borne, high-resolution seismic survey of Port Royal Sound

R. A. Gardner made high-resolution seismic traverses through the waters of Port Royal and St. Helena Sounds to determine the structure of Tertiary rocks. The depth of investigation was limited to 200 feet; the section includes post-Miocene clastic material, Miocene clastic material and limestone, and older limestones. The limestones have case-hardened layers whose seismic velocity is about twice as great as that of the other rocks. The vertical separation of the high-velocity layers was determined by geophysical data, which made it possible to map the top of the principal artesian aquifer within the limestones. A structural ridge in the upper 200 feet of sediments was determined to be colinear with the Yamacraw ridge in the basement rock.

GEORGIA

Spring-water supplies available in northwestern Georgia

A study of available water supplies in the Paleozoic rock area of northwestern Georgia by C. W. Cressler revealed that during annual low streamflows at least 115 springs each discharge more than 100 gpm. Of these springs, 47 flow more than 500 gpm, and 14 flow more than 2,000 gpm. The combined flow exceeds 97,400 gpm; during 1970, 86,200 gpm was unused except to maintain streamflow. Water from most of the springs is moderately hard to hard, has a low to moderate iron content, has a relatively constant temperature, and requires little treatment for use by municipalities and industries.

Hydrology of post-Oligocene sediments of coastal Georgia

Preliminary studies by E. A. Zimmerman and R. E. Krause of logs of wells penetrating post-Oligocene sediments in the coastal plain of Georgia indicated that the sediments were laid down in varied marine or marine-marginal environments; hence, the sediments are difficult to correlate. The sediments include varying proportions of water-bearing sand interbedded with relatively impermeable clay. The water-bearing sand beds can yield moderate amounts of water of good chemical quality; yields as high as 200 gpm and transmissivity as high as 6,700 gpd per ft have been recorded. Difficulties in well construction in the poorly consolidated material, the unpredictability of the sequence of beds, and the fact that an outstandingly productive limestone aquifer underlies the series have limited development of the post-Oligocene aquifer.

Water-level changes in Liberty and McIntosh Counties

R. E. Krause reported that near Riceboro, in southeastern Georgia, water levels in wells tapping the principal artesian aquifer apparently had been lowered below a level that could be attributed to regional decline. Extension of hydrographs indicated that 80 to 90 percent of the water-level decline in Liberty and McIntosh Counties during 1968 may be attributable to industrial pumping that began in March of that year. The decline was 3.3 feet at Harris Neck National Wildlife Refuge and 1.7 feet at Blackbeard Island National Wildlife Refuge, where flow from artesian wells had, in the past, filled fresh-water ponds. Pumpage had been fairly constant (about 9 mgd), and the water level had stabilized. The slope of the regional potentiometric surface in 1970 was slightly lower than it was in 1968.

Hydrogeology of southwestern Georgia

Study of ground-water resources in Sumter, Dooly, Pulaski, Lee, Crisp, and Worth Counties by R. C. Vorhis revealed that present use of ground water is less than 10 percent of annual recharge. Thus, water shortages should not inhibit economic growth of the six-county area. Prior study is needed, however, before drilling large wells (1,000 gpm or more). Nearly all water is now withdrawn from wells drilled in Tertiary rocks. As yet untested and untapped are deeper aquifers in Cretaceous rocks.

Effects of structure on water quality, Colquitt County

The postulated extension of the Ochlockonee fault into Colquitt County reported by C. W. Sever[73] is corroborated by the distribution of mineralized water from limestone of the principal artesian aquifer. E. A. Zimmerman found that wells near the trend of the fault yield water containing substantially more dissolved solids, especially sulfate, than others farther away. Thus, water quality reinforces the mapping of structure based on inadequate control. The fault is probably a conduit through which inferior water can enter the aquifer when pumping stress lowers the artesian head.

FLORIDA

Chemical type of water in Florida streams

Definition of the major-ion distributions under varying streamflow conditions, by M. I. Kaufman, resulted in (1) delineation of broad regions of the State wherein chemical-quality characteristics are similar, (2) correlation of low-flow chemical quality and ionic response to changes in streamflow with pertinent environmental controls, both natural and man influenced, and (3) illustration of the sensitivity of the dissolved solids–specific conductance relation to chemical type of water and concentrations of organic matter and silica, pointing to the need for knowledge of the water chemistry for accurate interpretations of specific-conductance data. The study was one phase in the portrayal of inorganic chemical-quality data for Florida on a regional basis.

Unused shallow zone of Floridan aquifer contains good water

Domestic wells along the middle Gulf coast of Walton County generally have been drilled to depths of from 350 to 450 feet in the Floridan aquifer, where both the quality of water and yields of wells are good. C. A. Pascale reports that good water is also available from a virtually untapped zone of the same aquifer at depths ranging from 80 to 100 feet. This zone ranges in thickness from 75 to 200 feet, and, although it is low in permeability, its yield is adequate for most domestic wells. This part of the Floridan aquifer is probably being recharged in south-central Walton County by water from the overlying sand-and-gravel aquifer.

[73] Sever, C. W., 1966, Reconnaissance of the ground water and geology of Thomas County, Georgia: Georgia Geol. Survey Inf. Circ. 34, 14 p.

Chemical and biological characteristics of the upper St. Johns River basin, Florida

A 1-yr investigation of surface water in the upper St. Johns River basin by D. A. Goolsby and B. F. McPherson indicated that water quality is greatly influenced by inflow of mineralized water from the underlying artesian aquifer. During low flow, dissolved-solids content ranged from less than 250 mg/l in tributaries to more than 1,500 mg/l at the downstream end of the study area. The dissolved-oxygen content and pH were generally lower in the tributaries and the upstream part of the river than in the lower reaches. The tributaries also had the highest concentrations of dissolved iron, carbon dioxide, and phosphorus. On the main stem, carbon dioxide and phosphorus decreased downstream. Total phosphorus loads from the tributaries were estimated to be 500 to 900 lb of PO_4 per yr per sq mi, whereas loads in the main stem were 200 to 300 lbs per yr per sq mi. Several lakes through which the river flows may be traps for the phosphorus, and, under near anaerobic conditions, the lake sediments may also be a source of phosphorus.

Concentrations of phytoplankton were usually low in the upper St. Johns; many samples contained less than 40 cells per ml. The most abundant planktonic forms were minute unicellular green algae. Two algal blooms were observed in 1970. One bloom was in an artificial impoundment and consisted primarily of the large colonial green algae, *Volvox aereus*. The second bloom was in a large lake and consisted mainly of the blue-green algae, *Anabaena circinalias*. Factors causing the blooms have not been determined.

Evaluation of the Pithlachascotee and Anclote Rivers for water supply

The Pithlachascotee and Anclote Rivers are being evaluated by R. W. Coble as potential sources of water supply needed to meet the increasing water demands in the rapidly growing resort and retirement area of the Gulf coast.

Both streams are tidal, and chloride concentrations of 250 mg/l have been detected as far as 6.8 and 10.8 mi above the mouths of the Pithlachascotee and Anclote Rivers, respectively.

At 90-percent flow duration, the combined discharge from both streams is about 2.7 mgd. Considerable quantities of water are discharged from the basins directly to the Gulf through the Floridan aquifer. This ground-water discharge especially affects the flow of the Pithlachascotee River, whose discharge per square mile is less than one-fourth that of the adjacent Anclote River. The potentiometric surface of the Floridan aquifer indicates that most of the water in the upper reaches of the Pithlachascotee basin discharges to the Gulf north of the Pithlachascotee estuary.

Geohydrology of the Highland ridge, Polk County

Water samples were taken from several zones in the Floridan aquifer by means of inflatable packers, according to A. F. Robertson. In the four wells sampled in the ridge area, the zones ranged from 150 to 700 feet below land surface and were marked by solution features, as indicated by caliper logs. Water quality varied little between the zones.

Ground-water withdrawal within the 250-sq-mi study area was estimated to be 70 mgd during 1970.

Runoff increased by canal drainage and irrigation in Indian River County

Streamflow records of a drainage district in eastern Indian River County, compiled by L. J. Crain, indicated that annual runoff in the area is about twice the runoff in undeveloped watersheds in that part of the State. The excess streamflow has previously been attributed solely to return flow of ground water pumped for irrigation. An analysis of streamflow records, water-quality data, ground-water levels, and irrigation-water use, however, indicated that about half of the increase in streamflow is caused by drainage from the extensive network of canals, which has lowered the water table and subsequently reduced open-water areas and other areas subject to substantial evapotranspiration.

Aquifer test, DeSoto County

Analysis of a 4-day aquifer test in northeastern DeSoto County, by W. E. Wilson, indicated that the limestone aquifer in this area has a transmissivity of several million gallons per day per foot. Wells being drilled for irrigation supplies in a 42-sq-mi citrus grove are 1,300 to 1,500 feet deep and yield about 2,000 gpm. On the basis of the aquifer test, drawdown in the aquifer at the grove well field would be 10 to 20 feet as a result of pumpage of 100 mgd for 100 days.

Urban hydrology, Venice area

According to Horace Sutcliffe, Jr., and Geronia Bowman, drainage from a dredge spoil from a sea-level canal may have adversely affected the water supply of Venice, a rapidly growing community south of Sarasota. Saline water encroached into the Venice well field after the dredging. The community has drilled four test wells, and more are planned south and west of town. The test wells yielded water of satisfactory quality, but maximum yield was only about 75 gpm.

Sea-water encroachment in the Loxahatchee River

Periodic conductivity measurements by H. G. Rodis in the main stem of the Loxahatchee River in Jonathan Dickinson State Park, southwest Florida, showed that saline tidal water invades the fresh-water environment of the upper reaches of the river during low flow. Cypress trees, which thrive in a fresh-water environment, are now dead along the banks of the middle reaches of the river—testimony of a fresh-water environment now episodically changed to a brackish-water environment. Land drainage, highway construction, and other construction in the Loxahatchee watershed cause flow characteristics and water quality of the river to continue to change.

Declining water levels in the upper Hawthorn aquifer in Lee County

A rapid increase in water use between 1966 and 1970 has resulted in a general lowering of water levels in the upper Hawthorn aquifer, which is the principal source of supply for Cape Coral, Fort Myers Beach, and Pine, Sanibel, and Captiva Islands in western Lee County. Studies by D. H. Boggess indicated that municipal pumpage increased from 0.5 mgd in 1966 to 2.5 mgd in 1970. Static water levels in areas adjacent to well fields declined an average of 5 ft per yr over this period. Currently, pumping levels range from 60 to 100 feet below land surface.

Before extensive development, the aquifer was predominantly recharged from the northeast. At present, hydraulic gradients have been established from coastal areas toward the well fields, thereby increasing the threat of salt-water intrusion. Other evidence suggests that ground water is being mined and that water may be in short supply within the next decade.

Water quality in Palm Beach County

Hydrogeologic studies recently begun by Howard Klein, H. G. Rodis, and J. J. Schneider show that urbanization is rapidly changing water quality in parts of Palm Beach County. Chemical analysis of water from a test well completed several feet below a sanitary fill at the Palm Beach County dump shows only moderate contamination; however, the dump is in an area where good to excellent water quality prevails. Test drilling in the Tequesta well field near the northeast coast shows saline water containing chloride in excess of 1,000 mg/l to be 15 to 40 feet beneath municipal wells. Ten years ago, the saline-water front was reported to be at least a quarter of a mile seaward. Locally, canals and lakes show coliform colonies in excess of 1,000 per 100 ml; the canals drain the Lake Worth drainage district, where fertilizer is heavily applied.

Water management in the Big Cypress Swamp

The Big Cypress Swamp in southwest Florida is an important water-resource area because it helps maintain an adequate seasonal supply of water for part of the Everglades National Park and adjacent estuaries, and it is a potential source of public water supply for the lower Gulf coast. An analysis of hydrologic and biologic data by Howard Klein (r0444), W. J. Schneider, B. F. McPherson, and T. J. Buchanan indicated that, although water supplies are adequate for urban expansion, an extension of urbanization by means of drainage canals in the central and eastern parts of the Big Cypress, and the pollution normally associated with urban growth, would alter the period of inundation and runoff characteristics of the swamp, would degrade the water quality, and thereby would cause environmental changes in a large part of the swamp and the park.

Potential fresh-water source in southwest Florida

Howard Klein and J. J. Schneider reported that geologic and hydrologic information obtained from exploratory rotary borings along the Everglades Parkway in southern Florida revealed an extensive section of highly permeable water-saturated limestone through an area across west-central Collier County. The maximum thickness of the limestone penetrated was 85 feet, and the water was low in chloride content. The section represents a large potential source of water supply for the expanding urban area in western Collier County.

Effects of drainage system on water resources, western Collier County

Specific-capacity tests by Howard Klein and H. J. McCoy indicated some hydraulic connection between canals of a large drainage system inland from the coastal ridge and the shallow sand and limestone aquifer in western Collier County.

It has been proposed that a controlled canal be constructed to parallel the municipal well field in order to recharge the field during dry periods. A quality-of-water monitoring network was established in the area to gather background data on the present quality of the ground water and to determine possible changes in quality after completion of the canal. Present data indicate that water in the area is virtually free of pesticides, nutrients, and sewage wastes.

Analysis of water-level data for Everglades National Park

Stage-duration and recession curves were prepared by T. J. Buchanan and J. H. Hartwell for five widely spread gaging stations in Everglades National Park. The stage-duration curves can be used to determine the hydrologic situation at the time of ecologic observations in this water-oriented park. The recession curves serve as a tool to estimate future water levels for the benefit of park management.

The hydrology of Taylor Slough

Taylor Slough, a small intermittent watercourse in Everglades National Park, contains ponds where wildlife can be viewed by visitors. The erratic annual rainfall, which averages 59 inches, resulted in annual runoff that ranged from 4.2 to 33.7 inches during 1961–68, according to J. H. Hartwell. During the same period, with the stage ranging from −1.4 to 5.0 feet, mean sea level, there was no flow 46 percent of the time.

Urban water problems and water management, Broward County

The continued population boom in eastern Broward County imposes a constant demand for increased fresh ground-water supplies and also represents a major source of contamination to these supplies. Thus, master plans call for the development of three well fields capable of yielding 100 mgd each, water-treatment plants, and two sewage-treatment plants for ocean outfall. These facilities will help to insure an adequate fresh-water supply through 1990 and should provide it a high degree of protection from contamination.

Studies by C. B. Sherwood, H. J. McCoy, and H. W. Bearden indicate that replenishment to the highly permeable Biscayne aquifer by rainfall and by infiltration from controlled canals of the regional water-management system will be sufficient to meet demands for fresh ground water if water management is strict.

The population of Hollywood, Fla., increased from 35,000 to nearly 107,000 (203 percent increase) between 1960 and 1970. The city's well field, adequate to meet present needs, is threatened by sea-water intrusion, and water needs may outstrip the present supply. Water data collected by H. W. Bearden indicate that areas west of the present well field would be best suited for expansion. Expansion of the present field would be limited by intrusion from the highly saline Hollywood Canal.

The population of the Hallandale area also has more than doubled since 1960. A rapid increase in water demands has resulted. Water-level contour maps by H. W. Bearden indicate that the northwest area of Hallandale is best suited for the development of additional ground water. Water-quality data indicate that many wells less than 100 feet deep were subject to ABS (nondegradable detergents) contamination, whereas wells cased to depths of 100 to 200 feet were not. New supply wells in this area are planned.

Recent diurnal nutrient studies by H. J. McCoy and C. B. Sherwood indicate moderate amounts of phosphorus (5 mg/l of P as PO_4) and nitrogen (5 mg/l of N as NH_4, NO_2, and NO_3) compounds in the Middle River Canal, Ft. Lauderdale. This canal is planned to furnish water to a feeder canal recharging the large (40 mgd) Prospect well field.

Countywide plans call for the Prospect field to supply the central part of the county with more than 100 mgd. The hydrologic system, thus, will be stressed, and water management may have to be strict.

Miami Canal recharge

The Miami Canal is the principal source of recharge to Miami's Hialeah–Miami Springs well fields. Head losses at the canal–aquifer interface are relatively high, according to F. W. Meyer and J. E. Hull, thereby indicating the presence of a confining layer or filter cake. Increased withdrawal from the well fields would deepen and enlarge the cone of depression about the well fields. Ultimately the cone of depression would intercept the tidal reach of the canal below the 36th Street salinity control unless the recharge capability above 36th Street is increased.

PUERTO RICO

Water in the Guayama area

The electric-analog hydrologic model of the Southern section of the Guayama area has made it possible to solve boundary problems satisfactorily, according to J. R. Diaz. The model effectively reproduces hydrologic situations comparable with field conditions.

On the basis of information obtained from the model, the aquifer is recharged from three sources: (1) underground flow through the valley alluvium, (2) infiltration from streams and irrigation canals, and (3) infiltration of rain. Steady-state simulation of the highest potentiometric distribution during the 1969 study period, under average pumpage of 2,027 acre-ft per yr, indicated that the total ground-water flow entering the area is about 6,400 acre-ft per yr. Infiltration of runoff from streams and recharge from rain is about 3,100 acre-ft per yr. Water entering the aquifer from the irrigation system is 202 acre-ft per yr.

Water discharged through lateral boundaries and to the sea is on the order of 4,250 acre-ft per yr. Water evaporated, transpired, and released from the aquifer to the lower reaches of streams is about 3,450 acre-ft per yr.

Water resources of the Yabucoa Valley

Test wells in the Yabucoa Valley penetrate more than 260 feet of alluvium, which overlies an irregular surface eroded into weathered igneous rocks, according to R. B. Anders and T. M. Robison. The alluvium is primarily composed of gravel, sand, silt, and bentonitic clay derived from granodiorite and allied rocks. Normally, 70 to 90 percent of the alluvium is composed of bentonitic clay and mixtures of bentonitic clay and silt, sand, and, locally, gravel. The remaining 10 to 30 percent is composed of mixtures of silt- to gravel-sized particles.

Aquifer tests and test drilling indicate that transmissivity ranges from nearly zero to more than 50,000 gpd per ft.

Water quality throughout most of the valley is excellent. Dissolved solids are normally less than 400 mg/l with the exception of the coastal area. Calcium-magnesium bicarbonate ground water predominates in the upper valley, where dissolved-solids content is less than 350 mg/l. Sodium bicarbonate predominates in the central part of the valley, where dissolved solids are generally less than 450 mg/l. The mineral content increases rapidly toward the coast, changing from sodium bicarbonate to sodium chloride water. Near the coast, dissolved solids may exceed 3,000 mg/l.

Transmissivity map of the south coast

A transmissivity map of the alluvial aquifer on the south coast of Puerto Rico has been compiled by G. D. Bennett and E. V. Giusti, using data from specific-capacity tests and pumping tests. The transmissivity distribution might have been predicted on the basis of the morphology of alluvial fans. The aquifer consists of a series of coalescing fans. Transmissivity is generally high toward the centers of these fans and along the axes of present and former channels, and is low in the intervening areas.

MIDCONTINENT REGION

The midcontinent region, although generally characterized by the availability of moderate to large supplies of water, has a number of problems relating to the quantity and quality of available water. Problems of quantity range from temporary excesses during floods to shortages during deficient periods of rainfall, as well as problems related to local areal differences in rocks, vegetation, and climate. Quality problems include those of salt-water contamination and the pollution of numerous streams and ground-water reservoirs by municipal and industrial wastes.

ALABAMA

Ecological changes in oil-field areas monitored

W. J. Powell and M. E. Davis report that since 1962 a network of ground-water observation wells and surface-water stations has been monitored to give warning of changes in the chemical character of both ground water and surface water in the principal oil fields of Alabama. The effectiveness of the monitoring system is credited with pinpointing three problems in oil-field practices in the past 2 yr that could have caused serious pollution problems if the State Oil and Gas Board had not been alerted to the problems at an early time.

INDIANA

Water resources in the Maumee River basin

Studies by R. A. Pettijohn and L. G. Davis indicate that the Maumee River basin in Indiana may be divided into three subareas on the basis of ground-water availability. The northern third, where the aquifer has an estimated transmissivity of 100,000 to 300,000 gpd per ft, has the best potential for development. The central third, where the aquifer's transmissivity ranges from 25,000 to 100,000 gpd per ft, has the second best potential for development. The southern third of the basin has the poorest potential for development; in this part, the maximum transmissivity of the aquifer is about 20,000 gpd per ft.

The average ground-water runoff is estimated to be 250,000 gpd per sq mi in the north, 175,000 gpd per sq mi in the central part, and 125,000 gpd per sq mi in the south.

IOWA

Bedrock topography of eastern and southern Iowa

Maps showing the elevation and configuration of the buried bedrock surface in a 34-county area in southern and eastern Iowa are being prepared by J. W. Cagle and R. E. Hansen. These maps depict the extensive drainage systems developed on the buried surface during preglacial and interglacial periods and also indicate the relationship between present-day and preglacial drainage systems. The buried bedrock valleys are of two types: narrow, steep-walled channels which cut into carbonate country rock, and relatively wide valleys with gently sloping sides in shaly terrane. Maximum relief in the vicinity of the bedrock valleys is about 350 feet.

The bedrock surface is covered nearly everywhere by glacial deposits that are locally more than 400 feet thick. Drilling data indicate that areas underlain by buried valleys generally are more favorable for the development of shallow ground-water supplies from the glacial deposits than are areas underlain by buried bedrock uplands. Significant sand and gravel deposits within or at the base of the drift in some of the channels have furnished yields of as much as 500 gpm to wells. The maps will be valuable tools for further exploration of shallow ground-water supplies.

KENTUCKY

Maximum yield of bedrock wells

D. V. Whitesides reported that, as a result of pump testing 106 wells in 41 counties, large quantities of water in the bedrock aquifers of Kentucky are available for development. Although about one-fourth of the wells tested have yields of less than 2 gpm, yields of as much as several hundred gallons per minute are not uncommon. Depths of wells tested ranged from 21 to 1,015 feet. New and better drilling and pumping methods, along with a better understanding of the occurrence and movement of ground water in bedrock aquifers, have made it feasible to drill wells to greater depths and tap more plentiful water supplies.

Water yields from the Green River alluvium

Studies by P. D. Ryder indicated that proper exploration can locate deposits of sand and gravel with relatively large water yields in the Green River alluvium. As a result of these studies, a well yielding 170 gpm was installed about 2 mi north of Delaware, Ky., and two wells which together yield 280 gpm were completed in the alluvium about 1.5 mi west of Calhoun. These wells are used for secondary oil recovery. The use of gravel-packed tubular wells yielding about 200 gpm, as at Island in McLean County, will become more common when the thickness and areal extent of this aquifer are mapped in detail.

Fault controls rate of ground-water-level decline

Water levels in wells in the sandstone aquifers of Pennsylvanian age in the western Kentucky coal field, north of a fault zone near Nortonville, Hopkins County, are declining rapidly, according to R. W. Davis, R. O. Plebuch, and H. M. Whitman. They also reported that the water levels at the municipal well at Mortons Gap, north of the fault zone, declined at a rate of about 11 ft per yr during the period 1954–65, and 50 ft per yr during the period 1965–70. During the latter period the pumping rate was 100 gpm as compared with 12 gpm for the earlier period.

South of the fault zone the water levels in the Nortonville city supply wells tapping the same aquifer declined only 100 feet during a period of 20 yr under pumping schedules and rates similar to those at Mortons Gap.

The decline of the water levels at both cities is attributed to the aquifer's low transmissivity (about 800 to 3,000 gpd per ft), low storage coefficient (about 0.0006 to 0.00006), and lack of recharge. At Nortonville, the decline in water level is about equal to the decline calculated from pump-test data; north of the fault, at Mortons Gap and adjacent area, the decline is much greater than can be calculated from pump-test data. The fault thus appears to be a hydrologic-discharge boundary when wells at Mortons Gap are pumped.

MICHIGAN

Data compiled on Michigan lakes

Data for 257 lakes in Michigan have been collected and presented in a report compiled by J. B. Miller (r0258) and Ted Thompson. The report contains a description of each lake, a list of discharge measurements made on inlet and outlet streams, quality-of-water data, location maps, and lake-stage hydrographs. Individual lake-stage records range in length from less than 1 yr to 31 yr. Data contained in the report will serve as a base for more comprehensive lake studies.

Chemical quality of streams studied

A reconnaissance of the chemical quality of Michigan streams at high and low flow was completed in 1971 by W. W. Wood. Natural stream quality is shown to be dependent on the geology and regional evapotranspiration, although disposal of municipal and industrial waste has altered water quality at some locations. Chemical concentration and physical properties were found to change very little from high to low flow.

Hydrologic influences on trout populations

In a study of hydrologic influences on recreational values of cold-water rivers of Michigan, G. E. Hendrickson and C. J. Doonan found that trout populations in 16 stream segments were significantly related to mean annual maximum water temperatures. A relationship between trout populations and variability of streamflow was also suggested, with the higher populations in the streams having a relatively stable flow. Multiple correlation of other hydrologic parameters, including mean discharge and 90-percent-duration discharge, in cubic feet per second and cubic feet per second per square mile, failed to show significant relationships to trout population. Further studies are being made with larger sampling and additional hydrologic parameters in an attempt to improve correlations.

MINNESOTA

Water resources of river basins in Minnesota

Studies in progress by W. L. Broussard, H. W. Anderson, Jr., and D. F. Farrell indicate that most cities (with the exception of the Twin Cities) in the Blue Earth, lower Minnesota, Cannon, and Zumbro River watersheds obtain their water supply from wells tapping rocks of Paleozoic age. In the Blue Earth River watershed, 33 percent of the cities obtain water from the Jordan Sandstone or other older Cambrian sandstone, and 22 percent obtain water from glacial drift. In the Cannon and Zumbro River watersheds, east of the Blue Earth, 65 percent of the cities tap Jordan and older Cambrian sandstone and only 12 percent obtain their water from glacial drift.

Low-flow measurements in the Blue Earth and lower Minnesota River basins indicate wide variations in ground-water runoff. Sand and gravel deposits along the lower Minnesota River yield as much as 7.9 cfs per mi in the reach between Blakeley and Jordan, compared to 1.2 cfs per mi in the lower reaches of the Blue Earth River between Winnebago and Rapidan.

According to H. W. Anderson, Jr., major flooding in the lower Minnesota River watershed usually results from spring snowmelt, although occasionally intense summer storms create floods. Flood damage is widespread because of the slight slope and broad, flat flood plain of the basin. The Blue Earth, Cannon, and Zumbro River watersheds are characterized by very high peak flows of short duration owing to the deeply incised streams and steep valley slopes in the lower reaches.

G. F. Lindholm, J. O. Helgesen, and W. L. Broussard found in their study of the lower St. Croix and Rum River basins that the Precambrian and Cambrian bedrock in all of the St. Croix River watershed and in the southern third of the Rum River watershed are relaible sources of ground water. Evaluation of surficial outwash in the lower St. Croix watershed indicates that yields of 100 to 500 gpm are possible over a considerable area. In areas of thin glacial drift overlying granite in the northern part of the Rum River watershed, there may be inadequate supplies of water for some types of development.

Ground-water movement in the upper Mississippi drainage basin in Minnesota is largely controlled by the streams. In the lower St. Croix River watershed, ground water moves eastward toward the river, opposite to the direction of dip of the bedrock.

MISSISSIPPI

Deep test drilling

E. H. Boswell, F. H. Thomson, and D. E. Shattles[74] reported that potable water was found in the lower Wilcox aquifer by a 1,934-foot test hole about 12 mi downdip from existing wells at Quitman in Clarke County, Miss. An industrial well constructed at the site had a natural flow of 1,080 gpm and a static water level 61.7 feet above land surface. Transmissivity of the aquifer was determined as 125,000 gpd per ft and the permeability as 900 gpd per sq ft. Chemical analysis of the water showed a dissolved-solids content of 251 mg/l, of which only 25 mg/l is chloride. The iron content was 0.04 mg/l, and the pH was 8.1.

R. E. Taylor reported that exploratory drilling in east-central Kemper County led to the discovery and exploitation of a 320-foot-thick bed of sand in the lower part of the Coker Formation (Tuscaloosa Group). A 2,367-foot well adequate for the needs of the 1,500 persons in the area and supplying water with 580 mg/l dissolved solids, of which 233 mg/l is chloride and 1.0 mg/l is iron, was developed in an area which had yielded water in excess of 1,000 mg/l dissolved solids from shallower aquifers. Transmissivity of the aquifer was determined as 700,000 gpd per ft, and the initial static water level was 4 feet above land surface.

MISSOURI

Storage facilities needed to insure water supply

John Skelton and J. H. Barks found that in the St. Louis–St. Charles–Jefferson County area, the median low flow (7-day Q_2) for rural tributary streams ranged from 0 to 0.005 cfs per sq mi in the northern two-thirds of the area, and from 0.02 to 0.05 cfs per sq mi in the southern one-third of Jefferson County. The data from urbanized areas indicate that the 7-day Q_2 is as large as 0.3 cfs per sq mi in basins where sewage treatment plants are operating. In almost all of the interior portions of the area, storage facilities are required to insure dependable surface-water supplies.

Data on flood runoff from Coldwater Creek basin, which is about 40 percent sewered and about 20 percent of which is covered by impervious surfaces, indicate that the mean annual flood is 1.9 times greater than that from a comparable rural basin.

[74] Boswell, E. H., Thomson, F. H., and Shattles, D. E., 1970, Water for industrial development in Clarke, Jasper, Lauderdale, Newton, Scott, and Smith Counties, Miss.: Mississippi Research and Devel. Center Bull., 62 p.

OHIO

Ground water in northern Ohio basins

A. C. Sedam reported that the best bedrock ground-water source in a 10-county area of northeastern Ohio is the Pottsville Formation of Pennsylvanian age. A porous, conglomeratic channel-fill sandstone, the Sharon Member, is the most productive unit and commonly yields 50 to 200 gpm to wells which reach it. Locally, yields from wells in the Connoquenessing and Homewood Sandstone Members are as large as those in the Sharon Member, but the presence of shaly facies cuts down on their overall productivities. Yields from all units diminish downdip to the south where, ultimately, the water is saline. These sandstone members of the Pottsville Formation tend to be more productive near their eroded margins where the development of fracture openings and contact with permeable glacial drift provide favorable conditions for recharge.

Continuing studies of the carbonate-rock aquifers in northwestern Ohio by S. E. Norris and R. E. Fidler (p. B229–B235; C202–C206) have resulted in a more precise definition of a previously recognized area of high ground-water yield and development of a hypothesis to account for its origin. The high-yield area is a long, striplike area, 7 to 18 mi wide, that winds for many miles along the flanks of the north-plunging Cincinnati arch.

The high-yield area is the probable result of ground-water solution acting over long intervals on a structurally controlled, periodically emergent peninsulalike landmass. The effects of solution are now largely restricted to the peripheral area of the original landmass as a result of subsequent erosion and removal of the beds that formerly made up its higher central part. The high-yield area is the principal area of recharge to the limestone and dolomite aquifers, as indicated by the relative undersaturation of the ground water with respect to calcium carbonate.

Identification of the high-yield area, to which future large-scale ground-water developments inevitably will be drawn, points the way to more effective exploitation of ground-water resources in northwestern Ohio. Of equal importance is the fact that conditions which produced the high-yield area were fairly widespread and not confined to northwestern Ohio. Similar belts or zones of high productivity in the carbonate-rock aquifers can be expected to occur in other parts of western Ohio, and perhaps also in the adjacent states of Indiana and Michigan, in association with structurally higher areas.

TENNESSEE

Effects of geology and physiography on base flow of upper Duck River

C. R. Burchett pointed out that within the upper Duck

River basin of central Tennessee there are two physiographic provinces, the Highland Rim composed of Mississippian-age formations and the Central Basin composed of Ordovician-age formations. The headwaters of Duck River are in the Highland Rim, which is about 300 feet above the Central Basin. The two areas are separated physically by a deeply dissected escarpment and geologically by the Chattanooga Shale aquiclude. About 60 feet of overburden, much of which is water bearing, covers the Highland Rim, whereas the overburden in the Central Basin is only about 20 feet thick and is not water bearing. In the Central Basin, water is stored only in the cracks, crevices, and solution openings within the bedrock; most of these openings are within 100 feet of land surface.

During a period of low flow, 30 streamflow measurements were made on Duck River and its tributaries. The maximum measured flow was 83.6 cfs (0.211 cfs per sq mi), which is 9.5 cfs more water than was measured at a point downstream that has 29 sq mi more drainage area. Most of this decrease in flow is the result of underflow through the solution openings beneath the streambed. Most of the underflow returned to the surface at points downstream; the flow at the mouth of the basin measured 80.5 cfs, or only 3.1 cfs less than the maximum measured flow upstream.

In the headwaters area of the Highland Rim, the base flow is low because the streams are not deeply incised and do not tap the water table. As the Highland Rim drainage area increases, the streambeds become more incised and are capable of capturing more ground water. The Highland Rim streams had flows ranging from 0.037 cfs per sq mi at the headwaters to 0.584 cfs per sq mi just below the escarpment. Streams in the Central Basin had measured flows ranging from 0.005 cfs per sq mi where Ordovician formations supplied water to over 0.3 cfs per sq mi where a combination of Ordovician and Mississippian formations supplied water. The largest flows per square mile in the basin are located just below the Highland Rim escarpment; the downward movement of ground water is stopped by the dense Fort Payne Chert and underlying Chattanooga Shale, and the ground water moves laterally to discharge into the Duck River or its tributaries. Generally, from just below the escarpment to the lower end of the basin the flow increases, but at a decreasing rate per square mile.

Water resources of the Center Hill Lake region

Soils, alluvium, and solution cavities in limestone bedrock are the sources of ground water to wells in the Center Hill Lake region of central Tennessee. A study by G. K. Moore and J. M. Wilson showed that maximum potential well yields are 100 gpm from the subsoil, 200 gpm from alluvium, and several thousand gallons per minute from solution cavities. Both low-yield and high-yield wells occur in groups, and the yields correlate with soil thickness, geologic formation, and topographic position.

Raw water from streams in the region generally meets the chemical standards recommended for drinking water. However, a few water samples contained more than 500 mg/l dissolved solids, or more than 0.3 mg/l Fe.

Average annual precipitation is 53 inches, of which evaporation and transpiration consume 36 inches, and 17 inches leaves the area as streamflow.

WISCONSIN

Storage requirements in a water-poor area

Potentially available surface water in a water-poor area in central Wisconsin greatly exceeds the present needs of municipal and large industrial supplies. However, great amounts of water in the streams run off too rapidly to be used as municipal supplies, and storage must be provided for dependable year-round supplies.

According to E. A. Bell and M. G. Sherrill, about 180 cfs-days of net storage, or 50 days' supply, would be required in the Big Eau Pleine River near Stratford, which is in the central part of the water-poor area, to sustain a uniform draft of 5 cfs at this site. The estimated net storage, excluding allowance for evaporation and reservoir losses, is within-year storage and is based on a 20-year recurrence interval. A draft of 5 cfs is equivalent to about 3 percent of the average flow (168 cfs) and about 10 percent of the smallest annual mean flow (47.5 cfs).

ROCKY MOUNTAIN REGION

Water-resources studies made by the U.S. Geological Survey in the Rocky Mountain region are designed to meet the constantly increasing demand for basic water data and for information required by planners and managers concerned with proper utilization of water resources.

The following examples of studies underway in cooperative programs with State and local agencies illustrate the wide range of activities within the region. In Colorado, a multilayered electric analog model for the San Luis Valley and a digital model of the stream and ground water aquifer system in the Arkansas River valley have been constructed. The models will be used in forecasting future changes related to development and use of the water resources of the two areas. Studies in the Judith basin of Montana indicate that aquifers presently used for water supplies on the periphery of the basin extend into the north and central part of the basin and provide water suitable for domestic and stock uses. Test drilling in the Sand Hills region of north-central Nebraska revealed that large supplies of water can be obtained from wells. Yields of from a few hundred gallons per minute to as much as 4,000 gpm are possible in parts of Custer and Blaine Counties.

A study of the ground-water hydrology of the Capitan Limestone in southeastern New Mexico and adjacent areas in Texas indicates that significant widespread lowering of the potentiometric surface in the aquifer has occurred. A study of climatic changes that have resulted in reported drying of some cave pools in Carlsbad Caverns, N. Mex., indicates that loss of moisture is due primarily to the flow of air up an elevator shaft and to heat added to the cave by the electrical lighting system. Test drilling programs in Cavalier, Griggs, and McLean Counties, N. Dak., have located buried glacial-drift aquifers that can provide as much as 500 gpm of water to irrigation, industrial, and municipal wells in favorable localities.

During the current year the results of research studies in the Rocky Mountain region have provided new techniques to evaluate water resources. Improved techniques in water chemistry, utilizing neutron-activation analysis, were developed to determine the amount of mercury and other toxic metals in water. New methods were utilized in field projects to measure vertical ground-water velocity with temperature profiles, to evaluate permeability of materials in the unsaturated zone with air pressure changes, and to identify chemical pollutants in water with borehole geophysical logging, using californium-252 as a source of neutrons.

An unusual hydrologic and geophysical research experiment is being undertaken at Rangely, in northwestern Colorado, to evaluate methods for control of earthquakes. Waterflooding has caused earthquakes along a fault at the margin of the Rangely oil field. Observations of earthquake activity were made with seismometers and well-recording instruments as water for secondary recovery of oil was injected into wells and later when the water was withdrawn. A marked decrease in earthquake activity was detected during the withdrawal period, presumably because of reduced fluid pressure in the reservoir.

The following discussions summarize results of some of the studies in progress in the region.

ARIZONA

Development of ground-water supplies at the Yuma Proving Ground

D. E. Click has found that a water supply of at least 350 gpm is available from the aquifer underlying the Castle Dome heliport at the Yuma Proving Ground. The ground-water supply was developed by the drilling and development of a deep test well. The water in the test well is of good chemical quality, except for the high fluoride concentration of 9 mg/l.

Geology and ground-water resources of Big Sandy Valley

The water resources of the Big Sandy area are only partially developed at the present time. According to E. S. Davidson, the ground-water discharge, made up of evapotranspiration and minor underflow, is about 14,000 acre-ft per yr, and the surface-water outflow is about 26,000 acre-ft per yr. The aquifer is very extensive and is more than 1,000 feet thick. The most permeable part of the aquifer underlies the Big Sandy River, where the aquifer, if dewatered, would readily accept recharge from surface flow. The chemical quality of the water generally is good. The fluoride content of most ground water in the area is greater than 1.2 mg/l and in much of the area is greater than 2.0 mg/l, which limits the usefulness of the water for drinking purposes.

COLORADO

Ground-water reconnaissance of northern and central western Colorado

In the northern and central parts of western Colorado (29,000 sq mi), A. J. Boettcher found that 68 of the 112 large-capacity wells (yield from 100 to about 1,000 gpm) tap the valley-fill deposits of the major stream valleys. The remainder of the large-capacity wells tap bedrock aquifers. The major bedrock aquifers are the Green River and Mesaverde Formations, the Dakota and Entrada Sandstones, and the Leadville Limestone. Springs and seeps discharge the largest amount of ground water in the project area and sustain flow in the headwaters of high mountain streams. In 1969 about 6,500 acre-ft of water was pumped from large-capacity wells, and about 6,000 acre-ft of water from springs was used by municipalities. Irrigation is the primary use of ground water. In many localities, the alluvial deposits could provide substantial additional supplies of water to wells for irrigation and other uses.

Hydrogeologic studies at the Rocky Mountain Arsenal, Denver

Studies by Robert Brennan and F. A. Welder indicated that a site for a new waste-disposal pond to accommodate waste generated from the detoxification of mustard and nerve gas at the Rocky Mountain Arsenal near Denver is underlain by at least 50 feet of sandy and silty clay of low permeability. The water table at the site slopes northward and is about 20 feet below land surface. The water contains as much as 790 mg/l NaCl, most probably derived from previous disposal of wastes. The investigation indicated that the site meets the environmental constraints required for a new disposal basin.

Multilayered analog model constructed for San Luis Valley

A multilayered electric analog model that simulates the upper 3,000 feet of the confined aquifer in the San Luis Valley has been constructed and interconnected with a previously constructed model of the unconfined valley aquifer, according to P. A. Emery. When the model is adjusted to adequately duplicate known hydrologic conditions, it will be used to make predictions. For example, the effects of change in irrigation-well withdrawals on streamflow and effects of changes in ground-water levels on aquifer storage can be simulated and analyzed.

Geophysical investigations in the upper Arkansas River basin

According to L. A. Hershey and A. A. R. Zohdy, surface resistivity surveys made in 1970 indicated that the thickness of alluvial fill in the upper Arkansas River basin near Buena Vista, Colo., may exceed 4,000 feet, and in the Wet Mountain Valley the alluvial deposits may be more than 6,000 feet thick. If these deposits are permeable, the potential for development of large ground-water supplies is great.

Digital-model study of the Arkansas River valley in Colorado

The percentages of applied irrigation water and of precipitation which recharged the ground-water reservoir were determined for 1964–68 using a digital model of the stream and ground-water aquifer system in the Arkansas River valley. O. J. Taylor and R. R. Luckey reported that 20 to 30 percent of applied irrigation water and precipitation recharged the shallow ground-water reservoir in the valley from Pueblo to the State line.

KANSAS

Potential for irrigation limited in Hamilton County

Use of ground water for irrigation in Hamilton County is limited by the lack of areally extensive aquifers, poor water quality, and rough topography, according to D. H. Lobmeyer and C. G. Sauer. Only 150 of the 990 sq mi in the county are underlain by aquifers having hydraulic conductivities and saturated thicknesses sufficient to yield 500 gpm or more to wells.

Water levels decline in northwestern Kansas

M. E. Pabst and K. M. Keene reported that water levels in 365 observation wells in nine northwestern Kansas counties declined an average of 0.9 foot in 1970. During this time, 400,000 acre-ft of ground water was pumped from 2,100 large-capacity wells. Water-level declines for the 5-yr period 1966–70 ranged from less than 2 feet in areas of little pumping to as much as 20 feet in areas of greatest pumping. The 5-yr declines averaged 2.9 feet in Cheyenne County, 1.5 feet in Decatur County, 2.8 feet in Rawlins County, 2.7 feet in Sheridan County, 6.4 feet in Sherman County, 2.6 feet in Thomas County, and 8.3 feet in southern Wallace County. Although data are not complete for all of Gove, Logan, and Wallace Counties, water-level declines during 1966–70 in the northern part of these counties probably averaged less than 3 feet.

MONTANA

Ground water in the upper Blackfoot River basin

Analyses of three aquifer tests indicate that the transmissivity of the alluvium along the Blackfoot River averages 45,000 sq ft per day. Transmissivity is much less in the glacial outwash and till. Ground-water flow to and from the Blackfoot River is controlled partly by the areal distribution of the alluvium, outwash, and till. These and other results of a study by D. L. Coffin and K. R. Wilke can be considered in planning the location and design of waste-disposal facilities for a proposed mining operation near the headwaters of the Blackfoot River. Contamination of water can be minimized by placement of waste in areas of low transmissivity having poor hydraulic connection with the river.

Ground water in the Judith basin

A study of the water resources of the Judith basin by R. D. Feltis showed that aquifers presently used for water supplies on the periphery of the basin extend into its northern and central parts and yield water suitable for domestic and stock use. Most drilled wells are in sandstone aquifers in the Kootenai Formation and, in some areas, the lower part of the Colorado Shale and the Eagle Sandstone. Wells in the Kootenai are as much as 2,460 feet deep and yield water that has a range in specific conductance of 560 to 900 μmhos/cm. The specific conductance of water from wells in the Colorado Shale ranges from 1,000 to 3,700 μmhos/cm, and the conductance of water from wells in the Eagle Sandstone ranges from 650 to 5,100 μmhos/cm.

Water resources of Glacier National Park

The U.S. Geological Survey, in cooperation with the National Park Service, has begun a study of the geology and water resources of Glacier National Park. Geologic mapping in 1970 on the west side of the park by R. D. Feltis, W. B. Hopkins, W. R. Miller, and A. W. Gosling has resulted in a preliminary differentiation of types of glacial deposits that overlie Tertiary sedimentary rocks and Precambrian metasedimentary rocks along the North and Middle Forks of the Flathead River. Outwash appears to be capable of storing and transmitting more water than other glacial deposits and may prove to be a dependable source of water for campgrounds and ranger stations.

Water resources of the Clark Fork basin

A study by A. W. Gosling showed that average precipitation on the Clark Fork drainage basin is 28 inches per yr and average runoff is 33 percent of precipitation. Average runoff in the four major tributaries of the Clark Fork ranges from 22 to 43 percent of average precipitation. Runoff from snowmelt and rain in April through July accounts for 70 to 75 percent of streamflow. Streamflow during the rest of the year is supplied predominantly by ground water. Ground-water inflow varies along the length of the stream. Large areas of Precambrian rocks and Cretaceous intrusive rocks contribute substantial inflows of ground water.

Deep aquifers in southeastern Montana

Water for secondary recovery at the Bell Creek oil field in southeastern Montana is obtained from two wells completed in both the Madison Limestone and the more deeply buried Red River Formation. One well initially flowed 0.3 mgd, and the other initially flowed 1.2 mgd. The wells are about 60 mi northwest of the nearest outcrop of the Madison Limestone.

The water is suitable for irrigation, though warm (49°C), and contains 1,040 mg/l dissolved solids, principally calcium carbonate and calcium sulfate. The distance of these wells from the outcrop indicates that water of relatively good quality may underlie part of southeastern Montana, according to W. R. Miller and W. B. Hopkins.

Inflow, outflow, and quality of water at Mission Lake

A study by L. R. Frost, Jr., of the quality of water in Mission Lake and in Two Medicine Canal indicates that these waters are significantly different. Water that flows into the lake from the canal is of the calcium bicarbonate type, containing 80 to 150 mg/l dissolved solids, whereas the water in Mission Lake is of the sodium magnesium sulfate type, containing 530 to 770 mg/l dissolved solids. During the spring of 1970 exchange of about half the lake's water, by diversion from Two Medicine Canal and by release from the lake, reduced the dissolved-solids concentration from 770 to 530 mg/l. The exchange had little effect, however, on the percentage reactance values of sodium, magnesium, or sulfate in the lake water. The unexpectedly small change may indicate a possible source of dissolved material other than the inflow from Two Medicine Canal.

NEBRASKA

Hydrogeology of the Nebraska Sand Hills region

According to F. A. Smith, test drilling in the eastern part of the Nebraska Sand Hills region revealed that large yields of water could be obtained from wells. Of 25 holes drilled in 1970, 19 penetrated the full sequence of sands and sandy gravels of Pleistocene age and silts, siltstones, and sandstones of Pliocene age. The average depth drilled was 665 feet, and the thickness of saturated sediments ranged from 200 feet (near the center of Custer County) to a little more than 775 feet (in Blaine County). Most of the holes were on two north-south lines about 33 mi apart and both nearly 100 mi long; the distance between holes was 12 mi. Although such wide spacing does not permit detailed correlation of stratigraphic units, it does provide an excellent basis for interpretation of regional subsurface conditions.

Well yields of as much as 4,000 gpm are possible in northwestern Custer County, where the Pleistocene sand and sandy gravel were found to be both highly permeable and thick. At this location the Pleistocene sediments fill a buried valley that has been cut into the finer textured Ogallala Formation of Pliocene age. Where the Pleistocene sediments are thin or consist mostly of sand, potential yields are less—at some sites no more than a few hundred gallons per minute.

At 13 of the test-hole sites, the aquiclude underlying the water-saturated permeable sediments is the Brule Formation of Oligocene age; at six sites it is the Pierre Shale of Late Cretaceous age.

NEW MEXICO

Fresh-water resources of the east side of the Tularosa Valley

Sergio Garza and J. S. McLean reported that nearly 11,000 acre-ft of ground water containing from 1,000 to 4,000 mg/l dissolved solids was pumped from the alluvial aquifer on the east side of the Tularosa Valley during 1969. Encroachment of inferior water has been detected 4.5 mi west of the irrigation well field, but the situation is not yet critical; excessive drawdowns in the well field may be of more immediate concern. The total volume of sediments dewatered by the withdrawal of more than 142,000 acre-ft of water during the period 1955–69 was estimated to be 1,600,000 acre-ft.

The maximum water-level decline to date is about 35 feet. It is estimated that the maximum decline would be 90 to 100 feet after an additional 20 yr of pumping at present rates.

Water-level declines in Capitan aquifer studied

W. L. Hiss is studying the ground-water hydrology of the Capitan Limestone in an arcuate area extending along the north and east margins of the Delaware basin in southeastern New Mexico and western Texas to determine whether withdrawal of water from the Capitan aquifer will deplete the aquifer and thereby cause water to be diverted from the Pecos River into the aquifer at Carlsbad, N. Mex., at some future time.

At Carlsbad the Pecos River is in hydraulic connection with the Capitan Limestone aquifer. Large amounts of moderately saline water are being withdrawn from the Capitan Limestone in southeastern New Mexico and western Texas and injected into other formations to repressurize partially depleted oil fields.

Water levels in five wells completed in the Capitan aquifer in southern Lea County (abandoned oil test wells) have declined at an average rate of 1.4 feet per month during the period 1966–70. Slight variations in the water levels, generally resulting in net long-term rises, have been detected in four observation wells (converted oil test wells) and in three additional observation wells in Eddy County during the same period.

The most significant lowering of the potentiometric surface in the Capitan Limestone aquifer is occurring in the vicinity of Kermit, Tex., where the potentiometric surface has been lowered approximately 500 feet during the period 1926–70 and is still declining at the rate of about 1.5 feet per month.

The permeabilities measured in the rocks of Guadalupe (Permian) age within the project area range from less than a millidarcy to several darcies. The permeability of the Capitan aquifer is much greater than the permeabilities found in associated sediments. Chloride-ion concentration maps showing the quality of water contained in rocks of Guadalupe age substantiate the conclusions that the hydraulic connection between the Capitan Limestone and other aquifers is poor.

Irrigation potential of the Ogallala Formation on the northern high plains

Examination of stratigraphic and geophysical logs and records of water levels for the northern high plains of New Mexico in Union, Harding, and Quay Counties, by E. G. Lappala, has shown that most wells obtain water from the Ogallala Formation and (or) the underlying Dakota Sandstone and Purgatoire Formation of Cretaceous age. Locally, adequate irrigation supplies are obtained from the Ogallala where it fills channels cut in Cretaceous rocks. In places, the Ogallala rests directly upon the Dakota and (or) the Purgatoire. However, in large areas the Ogallala is underlain by the Graneros Shale, which acts as a semiconfining layer to water in the Cretaceous aquifers.

The presence of this semiconfining layer in some areas, the erosional irregularities and structural undulations of the Cretaceous rocks underlying the Ogallala, and the multi-aquifer completion of wells—all cause complex hydrologic head distributions over the area.

Thus, analyses of short-term effects of pumping, including those of sophisticated aquifer tests, are relatively inconclusive for the northern high plains. Analysis of long-term areal effects of development, considering the Ogallala-Dakota-Purgatoire sequence as one ground-water reservoir system, will yield more useful information about the potential of the area for further development.

Causes of climatic changes in Carlsbad Caverns

In 1968 a study was begun in cooperation with the National Park Service to determine the cause of reported drying of cave pools in Carlsbad Caverns. J. S. McLean reports that the loss of moisture is due primarily to airflow up an elevator shaft and heat added to the cave by the electrical lighting system. The paving of parking lots over the cave, the air conditioning of the visitor center with air from the cave, and long-term changes in precipitation have had less significant effects on the climate of the caverns.

Chloride distribution in the shallow aquifer of the Roswell basin

Hydrologic studies of the Roswell basin by G. E. Welder included the preparation of an isochlor map of the shallow alluvial aquifer, which is separated from the deeper artesian carbonate aquifer by rock of relatively low permeability. The distribution of chlorides in the deeper aquifer has been determined several times in the past, but this was the first extensive sampling of the shallow aquifer. The cloride content of water samples collected from 180 shallow wells in August 1970 ranged from 20 to 3,700 mg/l and increased in the direction of ground-water movement. Conspicuous areas of excessive chloride east and northeast of Roswell (2,000+ mg/l) and surrounding Hagerman (3,000+ mg/l) are shown on the map.

Leaching of salts from the land surface and in the unsaturated zone by irrigation seepage of both ground and surface water is probably the principal reason for the high chloride concentrations. Upward leakage of salt water from the deeper aquifer in some localities, particularly northeast of Roswell, is probably a second source of chlorides. The water levels in both aquifers have been lowered by excessive pumpage. Consequently, upward leakage of fresh water from the deeper artesian aquifer to the shallow aquifer has been reduced. This in turn has reduced the natural ground-water discharge from the shallow aquifer to the Pecos River and the natural flushing of water through the shallow aquifer system. If water levels continue to decline, the chloride concentration in the shallow aquifer undoubtedly will continue to increase.

NORTH DAKOTA

Buried glacial-drift aquifer in Griggs County

Results of test drilling show that a large buried glacial-drift aquifer complex underlies about 100 sq mi of western Griggs County. A study by C. A. Armstrong reveals that the aquifer complex extends from Nelson County on the north and Foster and Eddy Counties on the west to the Spiritwood aquifer in Barnes County on the south. Saturated thickness and lithology indicate that potential yields to wells tapping the aquifer will be greater than 500 gpm.

Ground water in Cavalier County

Test drilling in western Cavalier County has located a glacial-drift aquifer that has an area of about 20 sq mi. R. D. Hutchinson reports that the aquifer will yield as much as 500 gpm of relatively good quality water. The Pierre Shale in south-central Cavalier County can locally yield as much as 50 gpm.

Piezometers installed at a site 6 mi west of the town of Cavalier show that the Dakota Sandstone is receiving a small amount of recharge through 300 feet of till and lacustrine clay. Water pumped from piezometers at this site shows that the dissolved solids increase with depth from about 230 mg/l at 20 feet to about 5,900 mg/l at about 300 feet in the Dakota Sandstone.

Buried valleys in McLean County

R. L. Klausing reported that test drilling in McLean County has revealed the presence of several buried interglacial valleys. These valleys contain saturated deposits of sand and gravel ranging in thickness from 70 to 200 feet. The largest of these buried-valley aquifers extends southeast across the county, a distance of about 80 mi. A reach of the aquifer about 20 mi long underlies the reservoir created by Garrison Dam.

These aquifers contain a predominantly sodium bicarbonate type water that ranges from 1,000 to about 1,800 mg/l dissolved solids.

Buried valleys contain major aquifers in Benson and Pierce Counties

P. G. Randich reported that results of the ground-water study in Benson and Pierce Counties show 7 million acre-ft of water in storage in glacial-drift aquifers within the two-county area. Well yields of 200 to 1,000 gpm are possible from these aquifers. Most of these aquifers are associated with part of the extensive northwest-trending buried-valley system in north-central North Dakota. The valleys represent a portion of the drainage linked to the ancient Spiritwood valley, which trends northward in the east-central part of the State. Some localized surficial and buried-outwash deposits that have potential well yields ranging from 100 to 300 gpm also were located. Water quality is generally within the U.S. Public Health Service standards.

OKLAHOMA

Availability of ground water in central Oklahoma

A reconnaissance study by R. H. Bingham and R. L. Moore of the water resources of the Oklahoma City quadrangle shows that several geologic units have considerable potential for development of ground-water supplies. Wells in the Garber Sandstone and Wellington Formation of Permian age yield from 50 to 450 gpm and average about 250 gpm in Oklahoma and Cleveland Counties. The water is suitable for most uses.

The alluvium and terrace deposits are an important source of water for irrigation. Wells in alluvium and terrace deposits along the major streams yield from less than 100 to more than 300 gpm locally.

The Vamoosa Formation of Pennsylvanian age has considerable potential for development of ground-water supplies in Seminole, Okfuskee, and Creek Counties, and in the eastern part of Payne and Lincoln Counties. Wells in the Vamoosa Formation yield from 25 to 200 gpm at the towns of Seminole and Cushing. Water from wells in the outcrop area of the formation is generally suitable for most uses. Locally, however, water in the Vamoosa may be polluted because of oil-field activities.

Yields of wells in the remaining parts of the quadrangle generally range from a fraction of a gallon per minute to about 20 gpm. The chemical quality of the water is generally poor.

Sources of ground water in the Oklahoma panhandle studied

The number of irrigation wells in the Oklahoma panhandle has more than doubled since 1964, according to studies by D. L. Hart, G. L. Hoffman, and R. L. Goemaat. In December 1970 there were about 1,800 wells in the area. Water levels have continued to decline at the rate of 1 to 5 ft per yr in the heavily developed areas.

Recent test drilling shows that the thickness of the Tertiary and Pleistocene material, including the Ogallala Formation, exceeds 600 feet in parts of northern Texas County. In this area the sands are separated by a thick clay section, creating a multi-aquifer system.

Test holes drilled in southwestern Cimarron County show the major aquifers to be the Cheyenne Sandstone Member of the Purgatoire Formation and Dakota Sandstone of Cretaceous age, but some additional water may be available from the underlying sandstones of the Morrison Formation and Dockum Group of Jurassic and Triassic age. Conductivity logging indicates that water in the Dockum Group is of considerably better quality than water in the overlying Morrison Formation.

SOUTH DAKOTA

Aquifers in north-central South Dakota described

Ground water of a quality suitable for irrigation can be obtained from shallow sand and gravel aquifers in Faulk, Edmunds, and McPherson Counties, north-central South Dakota, according to a study by L. J. Hamilton. Water from the aquifers has a low sodium (alkali) hazard; however, the deeper sand aquifers yield water having more than 1,000 mg/l dissolved solids. Such water is generally unacceptable for irrigation uses because of the high salinity hazard.

The total dissolved-solids content of water from the sandstone aquifers of Cretaceous and pre-Cretaceous age ranges from 2,000 to 2,500 mg/l and the water is unsuitable for irrigation. More than 90 percent of the dissolved solids in water from the Dakota Sandstone aquifer are sodium salts.

Water from the sandstone of the Fall River Formation and underlying pre-Cretaceous sandstones is a calcium sulfate type, and only 10 to 30 percent of the dissolved solids are sodium salts; the water may have moved upward from Mississippian-age limestones into the sandstone.

Glacial aquifer in Marshall County

A glacial artesian aquifer underlies an area of about 125 sq mi in the north-central part of Marshall County. Results of a systematic program, including test drilling and making a well inventory, by N. C. Koch and W. L. Bradford indicated that the aquifer is generally within 180 feet of the land surface and ranges from 20 to 90 feet in thickness. The depth to water in 14 observation wells ranges from 3 to 44 feet below land surface.

Availability of ground water in Charles Mix and Douglas Counties

An appraisal by Jack Kume of the water resources of Charles Mix and Douglas Counties, southeastern South Dakota, showed that these counties have important, but relatively undeveloped, ground-water resources. Six major alluvial and outwash aquifers occur in the surficial deposits. The Choteau sand and gravel, the largest of the six aquifers, underlies an area of about 200,000 acres and has an estimated 2,000,000 acre-ft of water in storage. The other five sand and gravel aquifers have a combined area of about 140,000 acres and an estimated 1,300,000 acre-ft of water in storage. Minor aquifers in the surficial deposits underlie about 90,000 acres and contain an estimated 350,000 acre-ft of water in storage.

Three of the glacial aquifers will yield water for irrigation and municipal well developments requiring more than 500 gpm. The other three will provide water supplies for developments requiring 250 to 500 gpm. Only the largest aquifer has had any large-capacity well development.

The major aquifers in the bedrock include the Dakota and Codell aquifers. The Dakota Sandstone aquifer underlies the entire area, has sufficient static head for flowing artesian wells in most of the area, and supplies moderate to large supplies of very hard, saline water. The Codell aquifer supplies most of the domestic, stock, and public-supply water and yields small to moderate supplies of soft, saline water.

Ground-water temperature studies in Beadle County

E. F. LeRoux reported that periodic temperature traverses run in a 500-foot well in Beadle County indicated that annual temperature fluctuations in the surficial glacial deposits are significant to depths of 30 to 40 feet. During one 12-month period the temperature at a depth of 20 feet ranged from 5.1°C to 10.5°C. However, at 40 feet below land surface the temperature ranged only from 8.9°C to 10°C.

TEXAS

Chemical quality of surface waters of the Rio Grande in Texas

A study by H. B. Mendieta of the chemical quality of surface water in the Rio Grande basin has shown that the kinds and quantities of minerals dissolved in the water are related principally to the geology of the strata underlying the drainage basin and to return flow from irrigation. During spring and summer, when water is released from reservoirs in New Mexico, the dissolved-solids concentrations of water in the Rio Grande at El Paso usually range from 600 to 700 mg/l. During fall and winter, when the flow at El Paso consists principally of seepage from Quaternary deposits and delayed return flow from irrigation, the dissolved-solids concentrations usually range from 1,000 to 2,000 mg/l.

Diversion of water for irrigation and municipal use results in almost complete depletion of flow in the reach downstream from El Paso. Return flows from irrigation upstream from Fort Quitman usually are saline. When a substantial part of the flow of the Rio Grande at Fort Quitman is return flow, the annual discharge-weighted concentrations of dissolved solids usually average from 1,000 to 3,000 mg/l.

Principal tributaries to the Rio Grande include the Pecos River and the Rio Conchos. Water from the Pecos River that traverses Quaternary deposits usually ranges from slightly saline to very saline; however, the inflow of less mineralized water from the Rio Conchos, which traverses deposits of Tertiary age, and from other tributaries and springs in the middle reach of the basin reduces the concentrations of dissolved solids in the Rio Grande.

During the period 1956–68, the discharge-weighted concentrations of dissolved solids for the Rio Grande at Laredo averaged 485 mg/l. Return flows from irrigation and other saline inflows have increased the salinity in the lower reach of the Rio Grande. During the period 1959–68, the discharge-weighted average concentration of dissolved solids for the Rio Grande at Anzalduas Dam was 684 mg/l.

UTAH

Water in western basins of Utah

Reconnaissance investigations of three western basins of Utah, all in Box Elder County, show common results. Western Utah is a semiarid region; even the highest parts of these small drainage basins receive little more than 20 inches of precipitation annually, and the valley floors receive less than 16 inches. As a result, runoff is small and is mostly ephemeral flow resulting from thunderstorms; likewise, ground-water recharge is small.

For Hansel Valley, J. W. Hood estimated the average annual recharge to be 11,000 acre-ft in a 237-sq-mi area. In Blue Creek Valley, E. L. Bolke and Donald Price estimated recharge to be 14,000 acre-ft in a 250-sq-mi area. For the Promontory Mountains area, Hood estimated recharge to be 12,000 acre-ft in a 360-sq-mi area.

In Blue Creek Valley, moderate additional supplies of ground water of suitable quality for irrigation, stock, and domestic use can be developed. Little additional development is feasible in Hansel Valley or in the Promontory Mountains area.

Water resources in National parks and monuments, Utah

Water-resources investigations were made by C. T. Sumsion in several National parks and monuments during 1970. In Canyonlands National Park in southeastern Utah the present water supply will be sufficient for near-future requirements in the park headquarters area. Future development of park facilities will be restricted, because of geologic and hydrologic controls, to small areas where ground water is of usable quality and quantity. In the Echo Park area (northwestern Colorado) of Dinosaur National Monument, a well completed in Weber Quartzite flowed 150 gpm; the water is of good chemical quality. Geologic and hydrologic investigations in the Herdina Park area of Arches National Monument in southeastern Utah indicate that ground water may be obtained by wells from the Wingate, Navajo, and Entrada Sandstones west of the park. Eight springs examined in Arches National Monument produce from 1 to 10 gpm of water of good quality from the Entrada Sandstone.

PACIFIC COAST REGION

The seven-State area of the Pacific coast region includes the diverse hydrologic and geologic terrane of the Arctic, the Pacific islands, and the Western States. The variations and contrasts in the hydrologic character of the region are reflected in the diversity of its hydrologic problems, which become more complex with increasing water use and resulting quality degradation.

Hydrologic problems in the region include natural disasters such as floods, droughts, and earthquakes; the effect of volcanic activity on ground-water reservoirs; sea-water intrusion into coastal aquifers; all forms of pollution; growth of population centers in water-deficient areas; water loss by evapotranspiration; construction projects such as the California Water Project and the proposed Alaska pipeline; deep waste disposal; mining of ground water; land subsidence; and the effects of urban development on streamflow.

Water-resources investigation and research studies are underway to help solve these problems. Some studies are designed to meet an immediate or local need such as locating a new water supply, forecasting flood flows, or determining time of travel of contaminants. Larger scale investigations include the hydrologic aspects of whole aquifers or entire river basins and are generally used in regional planning. Other studies delve into the research field with investigations such as the dynamics of glaciers, the ecology of lakes, the transport of radionuclides, and the digital modeling of streamflow.

The collection of basic data on streamflow, ground-water levels, chemical quality, water temperature, and sediment transport continues to be an important segment of work in the Pacific coast region. These are the data needed by planners and managers in their day-to-day operations and in their planning for future studies and projects.

In the above context, a significant effort involving three divisions of the Geological Survey—Geologic, Topographic, and Water Resources—has been launched in cooperation with the U.S. Department of Housing and Urban Development to make earth-science information useful to regional planners. The San Francisco Bay regional study, documented elsewhere in this volume (p. A170) includes water-oriented aspects such forecasting changes in flood runoff with increasing ubranization, studies of "real estate lakes," sediment-transport phenomena related to urban development, and mapping of areas likely to be inundated in the so-called 100-yr flood.

AMERICAN SAMOA

Water resources at Tafunafou

R. H. Dale reported that there is a supply of basal ground water of excellent quality at the village of Tafunafou. A test well produced 100 gpm with no measurable drawdown. The encouraging test results may lead the government of American Samoa to develop a Maui-type skimming well as a supply for Tafunafou and the three neighboring villages of Vaitagi, Iliili, and Mapusaga.

HAWAII

Water supply of central Maui

Contours of water levels in wells in the Maui isthmus indicate that ground water flows from west Maui to east Maui. K. J. Takasaki and Kenso Takumi found water of good quality in wells on the isthmus in east Maui and a poorer quality of water farther east on the lava slope; this indicates that there is an eastward movement of water and that recharge occurs west of the isthmus. The quantity of underflow has not yet been determined. If supplies prove to be adequate, the water most likely will be used for agriculture and livestock.

WASHINGTON

Water resources of the Yakima Indian Reservation

Water levels in some wells tapping the basalt aquifer in the Yakima Valley have declined more than 80 feet during the period 1960–70. The aquifer is recharged in part by leakage from the overlying sedimentary formation. D. O. Gregg, R. J. Burt, and E. G. Nassar found from a digital-model simulation of the basalt aquifer that the leakage is responsible for much of the winter recovery of water levels.

Effects of ground-water withdrawal in the Walla Walla River basin

Heavy pumpage for irrigation, municipal, and industrial supplies in the south-central part of the Walla Walla River basin has caused a decline of more than 100 feet in the potentiometric surface of the underlying basalt aquifer. In one small part of this area, a decline of 20 feet was recorded from June 1969 to January 1970 according to R. D. MacNish, D. A. Meyers, and R. A. Barker. Recently, a gravel aquifer which overlies 200 sq mi of the basalt aquifer has experienced local declines, believed to result from a change from furrow irrigation to sprinkler irrigation rather than from the increase in pumpage.

Ground-water availability in Chelan County and the adjacent Methow River basin

According to C. J. Londquist, most of the ground water presently used in the Chelan County–Methow River basin area is derived from glacial and alluvial sediments filling the major river valleys. Well yields from these materials range from 100 to more than 500 gpm; however, well yields from bedrock underlying the area are generally less than 20 gpm. The current total water requirement of 127,000 acre-ft per yr is satisfied from an estimated 1.5 million acre-ft of ground water in storage and an annual surface-water discharge of 5.2 million acre-ft per yr.

OREGON

Analog model of the dunes area of Coos Bay being constructed

Upper Pleistocene marine aquifers underlying the coastal dunes area north of Coos Bay have been developed for municipal-industrial water supplies. The area, which is 2 mi wide and 10 mi long and includes several shallow lakes, is used for recreation. J. H. Robison is determining how to obtain maximum yield with a minimum of adverse effects, such as lowering of lake levels or intrusion of sea water. A two-layer electric analog model is being built to predict future effects.

Water levels in Klamath basin suggest aquifer compartmentation

Compartmentation is suggested by a definite change in the configuration of piezometric levels within short distances in the volcanic aquifer of the Klamath basin, which is a good example of an area where a complex system of mostly northwest-trending faults could break the volcanic-rock aquifer into compartments. A. R. Leonard and A. B. Harris have noted several other places in Oregon where similar compartmentation occurs. In Yonna Valley no change in the piezometric gradient is perceptible across a major fault. However, in Langell Valley, piezometric levels differ by more than 50 feet on opposite sides of faults.

IDAHO

A proposed streamflow-data program for Idaho

The principal concept of the streamflow-data program is to provide needed information at any point on any stream in Idaho. The program consists of both data collection and analysis to furnish the streamflow information required for current needs, planning and design, and assessment of stream environment. According to C. A. Thomas and W. A. Harenberg the goals were to determine as many as 37 streamflow characteristics at any point on regulated and unregulated streams with an accuracy equivalent to that obtained by operating gaging stations for 10 yr on minor streams and 25 yr on major streams. Although the goals have been achieved on many principal unregulated streams, many of these streams still must be gaged to meet current data needs. Few goals have been achieved with available data on major or minor streams which are regulated, on streams which are fed by springs or large return flows, or on streams affected by extensive channel losses. The goals generally cannot be met on unregulated minor streams. More data are needed at existing sites and at new sites in order to progress toward further achievement of the established goals.

Ground-water movement into Rathdrum Prairie

Data supplied by a gravity survey and an exploratory well indicate that a ridge of relatively impermeable bedrock exists beneath the unconsolidated deposits east of Round Mountain. Interpretation of the data by R. E. Hammond reveals that the ridge is high enough above the regional water table to prevent the flow of ground water from the north along the east side of Round Mountain into Rathdrum Prairie. However, the gravity survey also indicates the presence of a river valley carved into the bedrock west of Round Mountain and buried low enough beneath the unconsolidated deposits to allow ground water to flow westerly from the north into Rathdrum Prairie.

NEVADA

Water resources of Big Smoky Valley

Ground water stored in the upper 100 feet of saturated alluvium in the northern part of Big Smoky Valley and in Tonopah Flat has been estimated at 5 million and 7 million acre-ft, respectively. F. E. Rush and C. V. Schroer[75] have estimated perennial yields from the valley-fill reservoirs of 65,000 acre-ft from the northern part of the valley and 6,000 acre-ft from Tonopah Flat.

Forty streams having a combined annual flow of about 35,000 acre-ft contribute to the ground water.

In an average year an estimated 4,500 acre-ft of surface water and 7,900 acre-ft of ground water are consumptively used in the northern part of the valley. It is estimated that annual ground-water consumption in Tonopah Flat is less than 1,000 acre-ft.

Hydrology of Lahontan Reservoir

New altitude-area-capacity relations were developed for Lahontan Reservoir in Churchill County by T. L. Katzer through the use of fathometer soundings, topographic maps, and aerial photographs. The new survey shows 16,000 acre-ft more storage space in the reservoir than was originally calculated in 1917.

More hydrographic areas investigated

In continuing water-resources investigations of hydrographic areas in Nevada, P. A. Glancy (r2504), J. R. Harrill[76, 77], and F. E. Rush[78] reported that 26 areas, or 10 percent of the total of 253, were completed this year, making the overall study 96 percent complete. Hydrologic budgets based on estimates of

[75] Rush, F. E., and Schroer, C. V., 1971, Water resources of Big Smoky Valley, Lander, Nye, and Esmeralda Counties, Nevada: Nevada Dept. Conserv. and Nat. Resources Water Resources Bull. 41. [In press]

[76] Harrill, J. R., 1971, Water-resources appraisal of the Granite Springs Valley area, Pershing, Churchill, and Lyon Counties, Nevada: Nevada Div. Water Resources, Water Resources-Reconn. Ser. Rept. 55. [In press]

[77] Harrill, J. R., 1971, Water-resources appraisal of Pilot Creek Valley area, Elko and White Pine Counties, Nevada: Nevada Div. Water Resources, Water Resources-Reconn. Ser. Rept. 56. [In press]

[78] Rush, F. E., 1971, Regional ground-water systems in the Nevada Test Site area, Nye, Lincoln, and Clark Counties, Nevada: Nevada Div. Water Resources, Water Resources-Reconn. Ser. Rept. 54. [In press]

runoff, recharge, water use, phreatophyte consumption, and other discharges were compiled for the following areas: Antelope (two by the same name), Deep Creek, Fireball, Groom Lake, Granite Springs, Indian Springs, Kumiva, Kawich, Mercury, Oasis, Papoose Lake, Rock, Pilot Creek, Three Lakes (southern part), Tikapoo and Tippett Valleys, Brady Hot Springs and East Walker areas, Buckboard Mesa, Crater, Frenchman, Gold, Jackass, Yucca Flats, and the Nevada part of the Great Salt Lake Desert.

Irrigation pumping in Paradise Valley

Fifty-three thousand acre-ft of ground water was pumped for irrigation in Paradise Valley, Humboldt County, during the period 1948–68. According to J. R. Harrill (r2505) and D. O. Moore this pumpage resulted in a net depletion of only 1,500 acre-ft of ground-water storage because of replenishment by infiltration of streamflow and reductions in natural ground-water discharge. The estimated yield of the system in Paradise Valley is 60,000 acre-ft per yr; an additional 8,000 acre-ft is derived from tributary areas.

Pumping in the southern part of the valley can probably salvage 15,000 acre-ft per yr of natural ground-water discharge without significantly affecting streamflow in the northern part of the valley or ultimately inducing appreciable underflow from beneath the flood plain of the Humboldt River.

CALIFORNIA

Inventory of lakes

J. C. Wallace (r2119), in his inventory of lakes, has found 142 California lakes with surface areas of between 160 and 640 acres. These lakes cover an area of 64,000 acres and contain 1.5 million acre-ft of water. The inventory furnishes such information as official name, local name, location, altitude, area, and volume.

Ground water in the San Joaquin Valley

According to R. W. Page the base of fresh ground water in the San Joaquin Valley occurs at depths of less than 100 feet to more than 3,500 feet, principally in unconsolidated deposits of Pliocene to Holocene age. In this study the base is taken at a specific conductance of 3,000 μmhos/cm (about 2,000 mg/l), a dissolved-solids content beyond which the water is not considered fresh. The base may reflect the configuration of the underlying structure, it may transgress the structure as it does along the eastern boundary of the valley, or it may transgress the major confining bed as it does near the southwestern boundary of the valley.

Locally, the fresh water is overlain by water with a dissolved-solids content that exceeds 2,000 mg/l. Nearly everywhere in the valley the fresh water is underlain by a basal saline-water body of a sodium chloride type.

Ground water in the Pajaro Valley area

K. S. Muir has found that the water-bearing Purisima Formation, which is exposed in the Soquel-Aptos area, dips to the southeast and underlies most of the Pajaro Valley area of Santa Cruz and Monterey Counties at an average depth of 700 feet. Few wells penetrate this formation because of its depth; however, water under artesian pressure may be a source of recharge to the overlying Aromas Red Sands of Allen[79] and alluvium, which are the utilized aquifers. The Purisima Formation is a potential source of ground water for Pajaro Valley.

The quality of the ground water presently pumped in the Pajaro Valley area generally is suitable for most uses.

Water wells and springs in Ivanpah Valley

Collection of basic data in Ivanpah Valley, San Bernardino County, led to the following significant findings according to W. R. Moyle: (1) Because of very little irrigation, industrial use, and domestic use of water there has been no appreciable change in ground water in storage between 1909 and 1969; (2) shallow wells surrounding the dry Lake Ivanpah have water of 200 to 1,000 mg/l dissolved-solids concentrations; water from shallow wells on the dry lake contains between 7,700 and 12,700 mg/l dissolved solids (a deep oil-test hole produced brine), and (3) ground water in Wheaton Wash has deteriorated owing to the percolation of mine and sewage waste water.

Dry springs in Joshua Tree National Monument

Many springs in Joshua Tree National Monument that formerly supplied water for wildlife have ceased to flow during the past several years, perhaps as a result of below-normal precipitation. G. A. Miller made reconnaissance studies of selected springs in the area, which indicate that the water table has declined below the spring outlets; however, saturated soil is within reach of the root systems of phreatophytes. Consumptive use by phreatophytes at most of the spring sites is estimated at several tens of gallons daily.

Ground water in the Joshua Tree–Yucca Valley area

According to R. E. Lewis, geohydrologic data of the high desert area in San Bernardino County indicate that: (1) The area is divided into five separate hydrologic subunits separated by barriers consisting of bedrock hills and faults; (2) major ground-water withdrawals are from subunits that supply the towns of Yucca Valley and Joshua Tree; (3) withdrawals of ground water since 1958 have caused water-level declines of as much as 40 feet near the town of Yucca Valley; (4) the quality of the water is good throughout most of the area, with dissolved-solids concentrations less than 200 mg/l, except near

[79] Allen, J. E., 1946, Geology of the San Juan Bautista quadrangle, California: California Div. Mines Bull. 133, p. 9–75.

the old dry-lake beds to the north where maximum values are nearly 2,000 mg/l; and (5) the concentration of fluoride ions generally is about 1 mg/l or less, but locally may exceed the maximum limits recommended by the U.S. Public Health Service.

Test drilling in Death Valley National Monument

Test augering near Eagle Borox Spring on the west side of Death Valley indicates that ground water containing 600 mg/l dissolved solids occurs at shallow depths under sufficient artesian head to produce flowing wells. G. A. Miller reports that the confining beds seem to be related to intertonguing of the alluvial fan deposits in which the water body occurs with the clayey deposits of the valley floor.

Spring flow in Death Valley National Monument

Texas Spring, which discharges along the west edge of the Furnace Creek syncline in Death Valley National Monument, has a remarkably constant flow. According to G. A. Miller, the discharge fluctuated between 170 and 215 gpm during 1968–70. During the period January 1970 to January 1971 the flow varied from 200 to 215 gpm. No apparent fluctuation in flow resulted from a flash flood in Furnace Creek Wash in June 1968, during which the peak discharge was estimated to be 5,000 to 10,000 cfs.

Test well in Yosemite Valley

A well was drilled near the center of Yosemite Valley to determine if ground water was available to augment the present surface-water supply at the national park headquarters. W. R. Hotchkiss reported that the well was drilled to refusal at 259 feet in a deposit of scattered boulders and silt; the top 56 feet of the well, in fine to medium sand, was screened for test pumping. The water was of excellent quality, but a discharge of only 100 gpm could be maintained.

Recharge to ground water from floods

Water levels rose to the highest points reached in several years as a result of heavy rains in central and southern California in January and February 1969. This abundance of rain caused a 216-foot rise in the water level in a well in the Lytle Creek area, San Bernardino County, according to J. L. Hughes.

Ground-water storage was increased by utilizing spreading grounds to which runoff from flooded streams was diverted. Reservoirs were used to increase ground-water recharge by releasing stored water after flood flows subsided. Recharge to ground-water storage from infiltration of runoff and direct precipitation was estimated to be at least 2.3 million acre-ft for nine major drainage basins. The value of the water added to ground-water storage was estimated at $60.6 million.

Water wells and springs in upper Santa Margarita River basin

A reconnaissance geologic map was compiled by F. W. Giessner showing locations of wells and springs in upper Santa Margarita River basin in Riverside and San Diego Counties. Basic data for these wells and springs have been coded for automatic data processing.

Ground-water outflow from San Timoteo–Smiley Heights

The configuration of the bedrock surface underlying the water-bearing deposits and the depth to bedrock in the San Timoteo–Smiley Heights area of upper Santa Ana Valley in San Bernardino and Riverside Counties have an important bearing on the hydraulic gradient and on the direction of ground-water flow. Three aquifers of greatly different permeability are present, according to L. C. Dutcher and F. W. Fengel. Faulting has compartmented the area and, locally, some faults form barriers to ground-water flow. The estimated total outflow declined about 34 percent during the period 1927–67; it was 2,800 acre-ft less in 1967 than in 1927.

Water quality near Box Canyon Dam and near Mineral King

The water quality of Lake Siskiyou, a new reservoir behind Box Canyon Dam on the Sacramento River 40 mi upstream from Shasta Lake in northern California, is being monitored under the direction of W. W. Dean. Bacteriological and chemical quality, including nutrients, were determined for 24 sites in Lake Siskiyou, in all its surface tributaries, and in the Sacramento River downstream. Preliminary results indicate very high quality except for above-average nutrient and coliform readings in certain tributaries and in the Sacramento River downstream from the lake. The high concentrations presumably result from waste discharges.

In the Mineral King area of the East Fork Kaweah River basin in the Sierra Nevada, Dean also is supervising the monitoring of quantity and quality of the runoff prior to development of a resort area. Monitoring began in 1968 at 17 sites and has covered the record high runoff of the 1969 water year and the below-average condition in 1970. All chemical, biological, and bacteriological data indicate extremely high quality, with low concentrations of dissolved constituents, dissolved oxygen at saturation, high species diversity and low densities of phytoplankton, and practically no suspended sediment.

Aquicludes in San Joaquin Valley

Unconsolidated deposits of Pliocene to Holocene age are the source of most of the fresh ground water in San Joaquin Valley. The unconsolidated deposits are divided into informal stratigraphic units on the basis of texture, mode of deposition, and source of sediment. This study is concerned with the delineation of extensive flood-basin, lacustrine, and marsh deposits. These deposits are gypsiferous and nearly impermeable and form the major aquicludes. They range from fine sand to silt and clay. Preliminary plotting of control points by G. L. Bertoldi indicates that the configuration of the major aquiclude (Corcoran Clay Member of the Tulare Formation) is a broad, northwestward-trending trough with the axis slightly west of the present-day valley axis.

Hydrology of eastern San Gabriel and San Bernardino Mountains and of Prado Reservoir

M. W. Busby has regionalized annual flow, flood frequency, monthly means, and high- and low-flow volumes for streams in the eastern San Gabriel and San Bernardino Mountains of San Bernardino County. These relations will permit the San Bernardino County Flood Control District to determine the quantity of water available for conservation through artificial recharge.

In another hydrologic study, Busby developed a daily-flow generator to synthesize 1,000 yr of flow data for the principal streams tributary to the Santa Ana River upstream from Prado Reservoir in San Bernardino County. A simple model was then developed to route these flows to Prado Reservoir.

Note.—Results of additional hydrologic studies in California, in the San Francisco Bay area, are reported on p. A170.

ALASKA

Water resources of the Greater Juneau Borough

Investigations in the Juneau area by J. A. McConaghy and W. A. Bowman showed that an abundance of surface and ground water is available for water supplies. The main problems are floods and short-lived droughts, suspended sediment in surface water, high organic color in surface and ground water, and high dissolved-iron content in some ground water. Most of the water sampled is the calcium bicarbonate type containing less than 500 mg/l dissolved solids.

Juneau receives an average of 94 inches of precipitation per year. Runoff from nearby nonglacial streams ranges from 60 to 80 inches per year, but basins in which glaciers occupy more than 10 percent of the area produce 125 to 290 inches of runoff per year.

Pumpage of 6 mgd since 1961 by the City of Juneau has not caused a significant water-level decline in the Last Chance Basin municipal well field.

Because of impending industrial development, more water data are needed at Berner's Bay, in the Eagle-Herbert Rivers area, at Point Bishop and Taku Inlet, and near Port Snettisham in the southern part of the borough.

Ground-water levels in the Kenai Peninsula Borough area

G. S. Anderson and S. H. Jones reported that ground-water levels dropped as much as 10 feet, to record lows, between the fall of 1967 and winter of 1969 in the Kenai area. Lake levels dropped as much as 6 feet, and several small streams ceased to flow.

A drought was the principal cause of declining water levels in 1968 and 1969. Yearly precipitation was only 11 inches where the normal average is 20 inches. Also, an increase in industrial pumpage from 0.2 to 2.4 mgd in 1970 may have been partly responsible. The extent of the Beaver Creek aquifer east of the city of Kenai was further delineated by test drilling in 1969–70, and a new production well was drilled 5 mi from the city.

WORLDWIDE AND INTERREGIONAL STUDIES

World's water balance

T. E. A. van Hylckama (U.S. Geol. Survey, r0632, p. A84–A85) reported that the seasonal shifting of masses of moisture from ocean to continent and back again contribute to the wobble of the earth. He computed the rate of movement using energy-balance equations rather than empirical methods based on temperature alone. The bulk data were reduced to grams per square centimeter. The mean storage has the components presented below:

Components of mean storage for the earth (g cm $^{-2}$)

I.	$0.19 \cos \odot$	$+0.77 \sin \odot$	$-0.08 \cos 2\odot$	$-0.03 \sin 2\odot$
II.	0.19	+0.60	−0.03	+0.07

The top line gives the data, which include data for water stored in vegetation, computed by Munk and MacDonald in 1960,[80] and the bottom line gives van Hylckama's (r1802) adjusted values which, however, do not include values for water stored temporarily in vegetation. The angle ($\odot$) is the longitude beginning with the 1st of January, 90° is about the 2d of April, and so on.

Water-supply studies by river basin and regions

In order to provide the Great Lakes Basin Commission with information for planning the water and related land-use development in the Great Lakes basin, R. M. Waller and W. B. Allen compiled data on well characteristics, chemical quality of ground water, aquifer potential, and saline-water occurrences. They also prepared a selected bibliography. Maps were made for each of the 15 planning areas, and tables were presented on well characteristics and chemical quality of each aquifer.

Preliminary calculations by R. M. Bloyd, Jr., suggest the presence and availability of vast amounts of ground water in the Ohio River basin. The ground-water system was divided into 15 units on the basis of the low-flow characteristics of the surface streams and on geologic information. The most productive source of ground water is the alluvial aquifer adjacent to

[80] Munk, W. H., and MacDonald, G. J. F., 1960, The rotation of the earth—a geophysical discussion: Cambridge Univ. Press, 323 p.

the main stem of the Ohio River. The saturated thickness of this aquifer ranges from 30 to 100 feet; the storage coefficient averages about 0.20 and the hydraulic conductivity about 3,000 gpd per sq ft. The potential pumping rate for an individual well is generally greater than 1,000 gpm.

A water-resources work group under the chairmanship of T. E. Eakin compiled data on the mean annual water supply for the Great Basin, excluding the parts of California and Oregon that are within the basin. These resources appeared to be on the order of 9.6 million acre-ft per yr, an estimate that is based on precipitation and streamflow records for the period 1931–60. About 60 percent of the supply is available from principal streams, about 24 percent from natural ground-water discharge, and the rest from secondary and minor streams. Withdrawals and depletions of water at the 1965 level of development were estimated to be about 8.7 and 6.0 million acre ft, respectively.

In the dry areas of Arizona and Nevada, C. T. Snyder studied the efficiency of artificially waterproofed areas used to channel rainwater into storage tanks for use during dry periods. The design for such catchments or rainfall harvesters must be based on the expected amount of rainfall and its distribution with time. With proper design, a balance can be achieved between need and supply, provided that the tank and catchment sizes are compatible with the expected rainfall. Local experience has shown that enclosed tanks are required to reduce evaporation and protect the water from gross contamination. Also, maintenance of the catchment surface is required to assure continued peak performance.

SPECIAL WATER-RESOURCES PROGRAMS

SALINE WATER

In the past, ground-water investigations were focused on an overriding practical consideration—was the ground water fresh? Contour maps showing the base of fresh ground water have been prepared for about one-fifth of the United States. These maps defined an imaginary boundary—laterally or with depth—beyond which, by inference, there was no need for study. However, it is now recognized that the occurrence of fresh water in regional aquifer systems is commonly a function of hydraulic controls in the saline parts of these systems. Hydrodynamic forces derive not only from fresh-water drive but also from sea-water drive, salt-diffusion gradients, geochemical and physical changes in water in sediments and bedrock, and geothermal heat flux.

A preliminary study of the occurrence of saline ground water indicates that saline water underlies more than two-thirds of the United States and that the depth to saline water is less than 500 feet below the land surface of more than one-third of the country. Porous and permeable rocks are found at depths as great as 15,000 to 20,000 feet. Thus, under at least one-third of the United States, fresh ground water occurs as a thin film overlying a very thick section of saline ground water.

The rapid development of desalting technology has brought with it recognition of a new intrinsic worth for this saline ground water. However, other values are assignable to the pore space occupied by saline ground water. Increased awareness of surface-water pollution and the need for protection of man's living environment have greatly intensified interest in use of saline aquifers (salaquifers) for disposal (permanent storage) of toxic industrial wastes. Near large metropolitan areas, the natural-gas industry uses salaquifers to store gas during summer for later recovery during the peak-demand winter heating season. In much the same way, fresh water can be injected into salaquifers as a fresh-water "bubble" for temporary storage and later recovery. Also, consideration is being given to the injection of saline water to gradually reduce shear stresses along fault zones before large earth movements produce destructive earthquakes. Thus, where saline water and salaquifers were considered unimportant a few years ago, they are now recognized as resources that must be carefully investigated, according to F. A. Kohout (r0953).

The U.S. Geological Survey defines saline water as containing more than 1,000 mg of dissolved solids per liter of solution. Water having salinities above 1,000 mg/l becomes increasingly bad tasting and undesirable. In the process of determining the market potential for desalting, the DuPont Corp.[80a] gathered chemical analyses for more than 18,000 cities and towns. It was found that 1,150 communities, serving a population of 3.5 million, had water supplies defined as saline. Over 6,000 communities, with a total population of more than 40 million, had water supplies that did not meet U.S. Public Health Service recommendations.

A. C. Sedam (r0774) (USGS) and R. B. Stein (Ohio Department of Natural Resources) have published a map showing the approximate base of fresh ground water for the State of Ohio. They report that some residents in west-central Ohio, northwest of Columbus, are using water from limestone aquifers that contains as much as 3,000 mg/l dissolved solids.

Owing primarily to drought-produced water shortages in the Northeast Corridor during the 1960's, investigations have been conducted in the New York–New Jersey area to determine the feasibility and economics of using polluted estuarine water as a method of "drought proofing." P. W. Anderson and J. J. Murphy report that chemical, physical, and bacterial analyses of feed water, brine blowdown, and distillate samples, collected at the Hackensack River pilot desalting plant in New Jersey from July 1968 to December 1969, indicate that the product water meets both New Jersey and U.S. Public Health Service drinking-water standards.

T. E. Kelly (r0330), B. N. Myers, and L. A. Hershey have mapped the saline ground-water resources of the Rio Grande region of Texas, New Mexico, and Colorado, an area of about

[80a] DuPont Corporation, 1969, Quenching a worldwide thirst: DuPont Magazine, v. 63, no. 1, p. 29–31.

136,000 sq mi. This cooperative pilot study between the U.S. Geological Survey and the U.S. Office of Saline Water was motivated by the desire to quantify fresh and saline water occurrences throughout a large region.

J. S. McLean (r0911) has provided information of sufficient detail to permit practical decisions concerning exploitation of both fresh and saline water in the Tularosa Valley (a subregion of about 4,000 sq mi in New Mexico). Fresh ground water was found to occupy alluvial deposits adjacent to the mountain front of this intermontane valley. Near the center of the basin, 6,000 feet of valley fill contained only saline water. The sediments saturated with fresh water amounted to less than 0.2 percent of the total, whereas 98 percent of the deposits contained water more saline (35,000 mg/l) than sea water.

DATA COORDINATION, ACQUISITION, AND STORAGE

Office of Water Data Coordination

The initiation of field-coordination activities and preparation of the "Federal Plan for Water-Data Acquisition" for fiscal year 1972 were the principal activities during 1970. Only those station activities concerned with continuous or daily measurement of surface-water flow were covered in this initial effort. Following the appointment of representatives for each of the Water Resources Council (WRC) planning regions by the Federal agencies involved with water-data activities, Office of Water Data Coordination (OWDC) field representatives contacted those individuals regarding agency plans for fiscal year 1972. From the information received, regional summaries were prepared for each of the WRC regions. In turn, these summaries were used to prepare a national report, "Summary of Plans for Acquisition of Selected Surface-Water Data by Federal Agencies, Fiscal Year 1972." The exercise showed that there would be little change in this type of data acquisition through fiscal year 1972; 365 new stations are proposed and 164, out of a total of 12,433 reported in operation on January 1, 1970, will be discontinued.

The agencies were asked to list data needs that are not being met, or which they anticipate will not be met, for all types of water data. One need that was emphasized by several agencies concerned a deficiency of data from small watersheds. In response to this statement of need, the Work Group on Hydrologic Data for Small Watersheds was formed to consider the various problems involved. In addition to the U.S. Geological Survey the group includes representatives from the following Federal agencies: Bureau of Reclamation, Bureau of Land Management, Forest Service, Soil Conservation Service, Economic Research Service, Agricultural Research Service, National Weather Service, Corps of Engineers, Federal Highway Administration, and Department of Housing and Urban Development. The work group agreed to assemble information on the present data base, after which they will evaluate the present programs and data and recommend ways to meet identified data deficiencies.

During the past year, four new positions were established, one in each of the Water Resources Division regional offices. Incumbents of these positions will serve as OWDC field representatives, as well as regional program officers for the Division, thus providing the necessary liaison between the data activities of the various Federal and non-Federal agencies in the field and the Water Resources Division data program. They are intimately involved in OWDC activities and particularly in the field-coordination procedures; they sense data needs, relate them to the ongoing data base, and help develop programs to meet the total data requirements. They are involved in the identification of the total long-term data requirements without regard to funding and operation.

Two interagency work groups, one on design characteristics of a data-handling system and the other on standards for water-data acquisition, completed their activities with preparation of two reports. A system for a National Water Data Exchange (NAWDEX) was proposed by the first group, and copies of the report have been distributed to members of the Federal Advisory Committee for review. A preliminary report setting standards for water-data acquisition, composed of the materials compiled by each of the six task groups, together with an introduction and summary of the task group recommendations was completed.

New indexes were published for the surface-water flow, the water quality, and the areal investigations sections of the "Catalog of Information on Water Data," with information on data-acquisition activities as of January 1, 1970. The maps for the surface-water and water-quality stations also were updated and published. The surface-water and water-quality sections were updated again as of October 1, 1970. The Mexican and Canadian governments were invited to contribute to the catalog by reporting data-collection activities in international river basins.

Water-data storage system

Data on daily discharge collected by the U.S. Geological Survey and cooperating Federal and State agencies at regular streamflow stations for about 220,000 station years of record are stored on magnetic tape. This covers more than 60 percent of all the streamflow data collected under this program. The data are stored in discrete units of daily figures for water discharge from each gaging station for each month; thus, the data are compatible with a variety of statistical programs for analysis on the basis of calendar years, water years, climatic years, or any other desired period.

An automated system of storage and retrieval of surface-water quality data has been used since 1959. All data collected since then, plus selected long-term historical records, have been entered into the system, within which they are separated into five basic groups as follows: (1) surface-water chemical and physical analyses, (2) suspended sediment, (3) water temperature, (4) specific conductance, and (5) multi-item data collected by digital monitors.

The Geological Survey has coded the data in machine format for about 35,000 ground-water wells and about 20,000 chemical analyses of water from these wells. The file, which uses the latitude-longitude system for locating wells, includes information relative to State, county, use of water, use of well, depth, drilling method, yield, water levels, physiographic data, and aquifer characteristics.

URBAN WATER PROGRAM

During the year, progress continued in hydrologic investigations in the urban environment. More than 320 projects of the U.S. Geological Survey were either directly or indirectly related to urban water problems.

Development of hydrologic methods for use in urban water studies

W. J. Schneider reported on research during the year on development of a practical field method for measuring flow in storm sewers under both open-channel and pipe flow conditions. A differential manometer has been developed by H. O. Wires for use in sensing pressure differential across an artificial constriction in pipe area to measure flow. Various pressure transducers are also being tested. Plans have been formulated for their installation in three different locations during the coming year.

G. F. Smoot reported that a water-quality sampling system is being fabricated for use in the urban environment. The sampler will take 24 2-liter samples and store them under refrigeration. The sampler has been especially designed for installation in storm sewers and can be programed to sample either with time or with flow.

A comprehensive program for hydrologic assessment of the Washington, D.C.–Baltimore, Md., urban area has been developed by W. J. Schneider and D. A. Rickert. The development of this program was coordinated with, and is part of, an overall program for appraisal of the natural resources of the area for urban planning. The hydrologic program consists of 30 basic components under 6 broad categories. A matrix is used to assign a priority rating to each of the basic hydrologic components on the basis of user need as related to urban water problems.

S. J. Stankowski reports the development of a rapid, inexpensive method for determining a quantitative index of urban and suburban land-use characteristics for use in regional water resources analyses. Population density is the only independent variable needed to utilize an empirical relationship for estimating the proportion of impervious area created by land-surface modifications resulting from varying degrees of urban and suburban development. This formulation is based on the use of a nonlinear correlation technique to relate population density to a weighted sum of the proportions of total land area contained within each of seven urban and suburban land-use categories. The proportions of land use are weighted by average percentages of impervious area representing the effects of typical urban and suburban land-surface modifications found in corresponding land-use categories.

The method is illustrated with county land-use and population density data for New Jersey. New Jersey is the most densely populated State in the Nation, with an average 1970 population density of 950 persons per sq mi of land area. The percentage of impervious land area corresponding to this population density was estimated to be 13 percent. For counties in New Jersey, percentages of impervious land area ranged from 4 to 45 percent for 1970 population densities ranging from 150 persons per sq mi to 13,800 persons per sq mi. This method is being used to generate indices of past, present, and future drainage basin land-surface conditions for use in an investigation of the effects of varying degrees of urban and suburban development on peak streamflow characteristics in New Jersey.

Studies of urban runoff and floods

Texas.—In cooperation with State and local agencies, Trigg Twichell is directing urban runoff studies in six areas in Texas. The broad objectives of these projects are to determine the effects of urbanization on the quantity, quality, and mode of occurrence of storm runoff. Studies indicate that design of an urban hydrologic program requires a relatively dense network of rainfall-runoff data-gathering sites so that a large number of rainfall-runoff events can be documented in a relatively short period of time. Immediate benefits can be derived from the data; from an examination of storm hydrographs, certain information can be obtained that can be used before sufficient data is available for a detailed analysis. Information on rainfall contributing to direct runoff and lag time between rainfall and runoff are examples of data that are usable immediately.

Because of the relatively small drainage areas used in an urban study, high return period rainfall-runoff data may be obtained even during periods of areal rainfall deficiency. Small, intense storms may occur under such conditions. Long-term data from a hydrologically uniform period are difficult to obtain in an urban area because of the constant changes taking place in an urban environment. After a model of the system has been developed, continuation of the program at its same level is necessary so that the model can be checked under similar conditions. Rapid adoption of the results for design purposes may cause significant changes in the study basins. Therefore, the data being collected to check the model may be from a hydrologically different period and may be unsuitable for use in checking the model.

S. M. Johnson and D. M. Sayre reported that in the metropolitan Houston, Tex., area 5 yr of peak-discharge data from 28 gaged drainage basins are being analyzed to relate peak discharge to the various basin parameters that affect the magnitude of discharge. The first phase of the study was devoted to modeling each of the basins to predict peak discharges, using the multiple-regression technique to develop a prediction equation. The independent variables used were precipitation duration and an index of soil moisture. Prediction equations for the 28 gaged drainage basins had a standard error of estimate that ranged from 9 to 63 percent, with the average being 29 percent.

The second phase of the study consists of deriving individual drainage basin flood-frequency relations by the following method: (1) rainfall records for 60 yr were applied to each drainage basin prediction equation; (2) annual peaks for 60 yr were then selected for each drainage basin; and (3) log Pearson type III frequency analyses were made for each of the drainage basins for 60 yr of predicted peak discharges. The third phase of the study consists of relating particular T-year floods to various basin parameters such as impervious cover and channel fall. Preliminary results show a high degree of correlation with a relatively small range (15–25 percent) of standard error of estimate.

Virginia.—Continued progress has been made in mapping of the flood plains in Fairfax County, Va. F. P. Kapinos and P. L. Soule reported that an additional 124 flood-inundation maps have been prepared during the current year. These maps cover 60.2 mi of streams in the county. The large-scale maps (1:1,200 scale with 2-foot contour interval) portray flood-hazard areas for floods having recurrence intervals of 25, 50, and 100 yr under conditions of ultimate urban development. Progress to date indicates that mapping of flood-hazard areas on large-scale maps can be done on a timely basis suitable for flood-plain management of rapidly developing areas.

P. L. Soule also reported that land clearing has caused a significant change in runoff characteristics of a 33-acre basin in Reston, Va., near Washington, D.C. The peak-discharge magnitude increased from a maximum discharge of 4 cfs for the period December 1966–September 1969 to a peak of 39 cfs for the 1970 water year. There has also been a noteworthy decrease in lag time for the drainage.

Strip-mined areas.—H. P. Guy reports an analogy between urban construction areas and strip-mined areas. Many hydrologic and, consequently, sedimentologic conditions are especially striking when compared with the rural or more natural drainage basins. In the United States, an average of 153,000 acres per yr are strip mined and 500,000 acres per yr are subjected to urban construction (calculated from a per-capita density of 5 per acre and an urban population increase of 2,500,000 per yr). When compared to the natural basins, both conditions usually result in a 50- to 200-percent increase in peak-flow rate, a 10- to 50-percent decrease in low-flow rate, a 5- to 40-percent decrease and a 20- to 100-percent decrease in time to peak for winter and summer storms, respectively, a twofold to thousandfold increase in sediment concentration, a threefold to four-thousandfold increase in sediment transport rate (difference in magnitude of increase between concentration and load is related to increased mean discharge), and a 10- to 200-percent increase in the dissolved-solids load.

Missouri.—D. W. Spencer and L. D. Hauth reported that flood-inundation maps have been prepared for two of the five principal drainage areas in the metropolitan St. Louis, Mo., area. The maps show the extent of flooding for the June 14–15, 1957, storm, determined by interviewing local residents and officials of the areas. The maps are interim reports of the project and provide the urban planner with information to delineate flood-prone areas. A flood-profile report, showing the effect upon flood profiles of construction on the flood plain of a 3,100-foot reach of a channel, is nearing completion. The report will present profiles for four conditions of the flood plain: (1) original ground elevations, (2) construction which took place between 1959 and 1969, (3) construction which took place in 1969, and (4) proposed floodwalls in place to protect buildings constructed during the 10-yr period.

North Carolina.—A. L. Putnam reported that results from five study areas in North Carolina indicate that storm sewering and impervious land cover decrease the overland flow time and infiltration rate, resulting in an increase of the total rainfall reaching a stream as runoff. Also, the amount of impervious surface appears to be the most accessible parameter for indicating the amount of storm sewering within a watershed. Previously, many investigators have used a family of curves, each depicting a different degree of urban development, to relate basin lag time to the stream length divided by the square root of the stream slope ($L/\sqrt{S}$). Putnam's studies show that one curve to estimate basin lag time can be defined by including the ratio of impervious surface to total drainage area as a parameter in the lag-time relationship. The use of one curve greatly reduces the subjectivity of interpolating between several curves individually based on a specific condition of development.

In the definition of peak discharges, use of a fixed ratio of a less frequent flood to one of a more frequent occurrence has been avoided. All levels of recurrence interval are defined by exponential equations where peak discharges are a function of drainage area and basin lag time. The exponents of drainage area and basin lag time, as well as the coefficients for these peak-discharge equations, define a smooth curve when plotted against recurrence interval on logarithmic probability paper.

Hydrology of sanitary landfill sites

New York.—A. D. Randall and D. A. Rickert are studying two new landfill sites in Halfmoon and Catskill, N.Y., to develop criteria for site selection and monitoring of sanitary landfills. The site-selection portion of the project involves determination of the rates of infiltration and leachate production under various soil and geologic conditions. The monitoring portion is closely associated, but it is directed at determining the water-quality parameters, frequency of analysis, and general sampling schemes that are required to effectively monitor a sanitary landfill. At each site, water quality will be examined in both the saturated and unsaturated subsurface zones, as well as in nearby streams.

Florida.—J. W. Stewart and A. D. Duerr are studying two active sanitary landfill sites in Florida to determine the effect on water resources of disposing solid waste into shallow trenches excavated below the water table in a sand and silt aquifer overlying a limestone aquifer. Slight ground-water mounds have developed in areas of completed trenches at both sites. However, the general direction of ground-water movement is the same as before operations began at these sites. When the sites were activated, a water-quality network of wells, canals, and springs was placed in operation to monitor the movement of leachate from the landfills. Data collected at both sites do not show contamination of the water from landfills except in those areas where a number of test holes were drilled within a few feet of the landfill trenches.

Maryland.—Studies by E. G. Otton showed that sanitary landfill sites occupy nearly every type of terrane in the State of Maryland. The geohydrology of the various terranes has been evaluated to appraise their hydrologic suitability for solid-waste disposal purposes. Chemical-quality monitoring of water draining from three active sanitary landfills during 1970 showed that leachate degradation of the water was occurring at two of the sites; at the third site the results were inconclusive. However, the third site had been an active landfill for only a short period of time prior to the start of monitoring.

Urban water-resources studies

Massachusetts.—J. E. Cotton and D. F. Delaney report that a study of ground-water levels in Boston, Mass., indicated that a major source of recharge to the ground water was water-main leaks. Pitometer surveys indicated that water loss from 167 mi of main was about 2.5 mgd or about 0.015 mgd per mi of water main. If distributed evenly over the Boston peninsula, this would be a recharge rate of 0.73 mgd per sq mi. While some of this water becomes a part of the general ground-water regimen, the travel distance for much of this recharge is probably very short. The water moves through the backfill and discharges into leaky storm and sewer mains and into openwork underdrains, which were originally installed at a slightly lower level to keep trenches dry during installation of the other lines. This study indicated that, in cities where most of the precipitation falls on buildings and pavement and is removed by overland runoff and storm drains, leaky water mains must be considered in the quantitative study of ground-water budgets.

Minnesota.—R. F. Norvitch reported that aquifers underlying the Minneapolis—St. Paul, Minn., metropolitan area which may be considered as hydrologic units are: (1) glacial drift, (2) St. Peter Sandstone, (3) Shakopee and Oneota Dolomites and Jordan Sandstone, (4) Ironton Sandstone Member of the Franconia Sandstone and Galesville Sandstone, and (5) Mount Simon Sandstone and Hinckley Sandstone of Winchell (1886).[81] In 1969, pumpage from these units in the metropolitan area was roughly 66.5 billion gal compared with surface-water pumpage from the Mississippi River of about 48.5 billion gal. The major aquifer is the Prairie du Chien (Shakopee-Oneota)—Jordan hydrologic unit. Local long-term water levels in this unit decline approximately one-half foot per yr (based on peak recovery periods), whereas in the Mount Simon—Hinckley unit, a secondary source of supply, water levels decline 7 to 10 feet per yr. Although declines in the major aquifer are not proceeding at an alarming rate, the progressive increase in pumping is causing greater combined water-level drawdown during peak withdrawal in the summer. Lower pump settings in some established wells in the core area have been required because of the increased drawdown.

Pennsylvania.—An analysis of streamflow data showed that a significant amount of streamflow is lost in the Cobbs Creek system, an urban stream near Philadelphia, Pa. Several discharge measurements, made on the same day by R. A. Miller, E. L. Smith, and R. L. Druther during low flow, indicate that the losses resulted from streamflow entering the storm sewer system through the sewer outfalls. This situation has occurred because of the silting in of the stream channel, most probably as a result of the urbanization of the basin. It is estimated that an average of 5.6 inches of water over a drainage area of 22.0 sq mi is lost annually. This loss is equivalent to 9.10 cfs or 6.0 mgd. After entering the storm sewer systems, the water is transported to the local sewage treatment plant where it represents 4.5 percent of the plant's treatment capacity.

New York.—N. M. Perlmutter reports that mapping of the subsurface hydrogeologic framework of Nassau County, N.Y., is being revised. The study will provide a detailed base for advanced studies of water contamination, interference between pumping wells, declining water levels, and construction of analog models. Significant hydrogeologic data for more than 500 deep wells are being coded.

G. E. Seaburn and D. A. Aronson compiled basic data pertaining to 2,124 recharge basins in operation in January 1970 on Long Island, N.Y. These data include location, date of construction, capacity to store water, maximum infiltration area, basin size, bottom elevation, overflow elevation, land-surface elevation, water-table elevation, drainage area, basin efficiency, use, geologic environment, and soil environment. They also found that 196 (9 percent) of the 2,124 basins are clogged. (Clogged basins are defined arbitrarily as basins holding water 5 days after a 1-inch rainfall.) Causes of clogging were found to be: (1) strata of low hydraulic conductivity between the basin floor and the water table, (2) sediments of low hydraulic conductivity deposited on the basin floor during storm runoff, and (3) a combination of these factors. Distribution of the clogged basins by character of the area drained is as follows: 8.3 percent of residential basins, 9.9 percent of highway basins, 20 percent of industrial basins, and 38.2 percent of commercial basins.

On the basis of detailed studies at basins in Deer Park, Syosset, and Westbury, Long Island, an average of 7, 10, and 12 percent, respectively, of the rainfall entered the recharge

[81] Winchell, N. H., 1886, Revision of the stratigraphy of the Cambrian in Minnesota: Minnesota Geol. Survey 14th Ann. Rept., p. 325–337.

basin as inflow. These percentages were about the same as the percentage of street area in the total drainage area of each basin. Average infiltration rates recorded during many storms ranged from 0.19 fph at the Deer Park basin to 0.75 and 0.91 fph at the Syosset and Westbury basins. The estimated average annual ground-water recharge at the three test basins was 30.3 acre-ft at Deer Park, 10.6 acre-ft at Syosset, and 6.6 acre-ft at Westbury. The estimated annual ground-water recharge from 2,124 recharge basins was 62 mgd. Analysis of precipitation and inflow samples showed that the recharging water generally is of good quality and that precipitation is the major source of the dissolved constituents. Significantly, high concentrations of pesticides were found in sediments from the floor of each basin.

G. E. Seaburn (p. D219–D223) also reported on the development of a procedure for measuring runoff in a storm sewer. The procedure resulted from a study of recharge basins on Long Island, N.Y., requiring accurate inflow records; it consists of recording fluctuations in stage in a rectangular manhole before the flow enters the basin. A theoretical rating curve between stage and discharge was developed using the critical-flow relationship and the Bernoulli equation. To verify this curve, a rating for the local storm-sewer system was developed from flow measurements of water supplied by nearby fire hydrants. Three methods were used to measure flow: volumetric, current-meter, and critical-flow measurements. The field-determined rating curve and the theoretical rating curve were nearly identical for the range of the field tests. Instantaneous discharges exceeding the field rating curve were evaluated by using the extension of the theoretical rating curve.

Philip Cohen, D. E. Vaupel, and N. E. McClymonds (p. C210–C214) reported that during the period 1962–69 the average MBAS (methylene blue active substance) content of 46 streams in Suffolk County, Long Island, was, on a yearly basis, approximately inversely related to the amount of streamflow. This relation partly reflected (1) the close similarity between the quality of the shallow ground water and the quality of the streamflow, coupled with the dilution effect of recharge from precipitation on the quality of the shallow ground water, (2) areal differences in the MBAS content of the shallow ground water and the effects of these differences on the quality of the streamflow as the headwaters of the streams shifted in response to the 1962–66 drought, and (3) the substitution of LAS (linear alkylsulfonate) for ABS (alkylbenzenesulfonate) in 1965. The average MBAS content and load of the streams in 1962 were virtually the same as in 1969. However, during the same period the average chloride content and load of the streams increased.

Nebraska.—F. B. Shaffer reported that more than half the low-flow discharge of Salt Creek at Lincoln, Nebr., is water that has passed through the Lincoln municipal sewage treatment plant. The entire public water supply at Lincoln, population 149,518 (1970 census), is obtained from wells, most of which are near Ashland, Nebr., at a site outside the Salt Creek drainage basin, and nearly all the waterborne wastes from the city undergo treatment at the plant. As the treated water discharged into Salt Creek is less saline than the natural low flow of the creek, downstream irrigators who pump from the creek have a water supply that is both greater and of more suitable quality. The water is used to irrigate about 3,500 acres of farmland.

Alaska.—The cooperative geohydrologic study of the Greater Anchorage Area Borough, Alaska, continued during the 1971 fiscal year. During the year, assistance was provided to the city of Anchorage in locating a new production well in the North Fork Campbell Creek fan area. According to R. S. George, a 1- to 2-mgd yield could be obtained from a well in this area. Work continued on the analog model of the Anchorage confined water system, according to W. W. Barnwell and J. B. Weeks. A satisfactory historical calibration of the transient-state solution has been made. Results based on analog-model analysis and on field data indicate that the best potential for production wells of maximum yield and small drawdown may be in the area south and east of the city center. An artificial-recharge site for the confined aquifers was prepared for testing after experimentation using the analog model. About 1 mgd of water will be diverted from Ship Creek into the surface spreading pond at the recharge site during the field testing. Increased emphasis was placed on analysis of the unconfined aquifers in the area. Drainage and reclamation of low-lying areas pose a threat to existing lakes. Also, L. L. Dearborn reports that some observation wells in the Anchorage area recorded all-time low water levels in the spring of 1970.

New England.—In the New England area, studies indicate that the deicing of roads causes local ground-water contamination. S. J. Pollock reported that the application of highway deicing chemicals, mainly sodium chloride and calcium chloride, by the Massachusetts Department of Public Works increased to a record high of 202,000 tons in the winter of 1969–70. Observation wells alongside State highways showed marked increases in chlorides in some places during 1970. At one site, the chlorides exceeded 250 mg/l for the first time since the wells were installed in 1965. At another site, the chlorides increased from a previous high of 12 mg/l in March 1970 to 66 mg/l in January 1971. Six actual or potential chloride problems, mainly associated with new highways, were investigated during 1970, compared with a total of five problems investigated during the 1965–69 period. The fact that chlorides, once they enter the ground water, can remain there for very long periods of time was demonstrated during 1970 when the chlorides in a municipal well located about 1,100 feet from a salt storage pile increased to a new high of 213 mg/l. The salt storage pile had been covered and placed on a pavement in 1967.

H. A. Whitcomb reported that ground-water contamination from highway salt at most of the monitoring sites in New Hampshire increased during 1970. At one site, water in a well 250 feet from the highway showed evidence of salt contamination for the first time; chloride concentration rose from 12 mg/l in March to 43 mg/l in August and remained high for the rest of the year. The highway was completed in 1959, so apparently it required about 10 yr for the contaminated water from the first winter's application of highway salt to move from the roadside to the affected well. The water table at the roadside is about 30 feet below the land surface. The material penetrated by the well is principally very fine to fine sand.

Florida.—In southern Florida, appraisals of the water resources in relation to persistent urban influences continued during the current year. F. W. Meyer and J. E. Hull reported that deteriorating water quality was a principal concern in Dade County during the year. In an evaluation of the master plans for water and sewers, F. W. Meyer reported that corrective measures call for the use of ocean outfalls. The one-time use of the water, however, will require a like reduction in runoff in order to provide sufficient fresh water for all future needs. Hull reported that peak pumpage by the city of Miami reached 212 mgd during May 1970. He also reported that during 1970 salinity concentrations increased in some wells of the city of North Miami Beach as a result of increased pumpage and the close proximity of the wells to the salt front. This is a reversal of the previous slow seaward movement of the salt front during 1961–69.

H. G. Stangland reported that construction of Walt Disney World, Fla., in the Reedy Creek Improvement District caused temporary increases in sediment loads to streams. Suspended-sediment loads of as much as 240 tons per day were flushed out of Bay Lake when the lake was drained. Increased total runoff from the swampy Reedy Creek basin, which drains the west half of the Reedy Creek Improvement District, has resulted in a channel scour of about 1 foot, a tenfold decrease in sulfate concentration, and a shift in the color-discharge relationship.

Urban effects on lakes

D. A. Rickert reported on the continued impact of urbanization on Lake Anne, a 7-yr-old manmade lake in Reston, Va., near Washington, D.C. The lake is highly eutrophic but has not exhibited algal blooms. Nutrients enter the lake in direct runoff from fertilized lawns and gardens, and from storm-water runoff of streets and parking lots. Simultaneously, large quantities of soil sediment enter the lake from cleared and incompletely restabilized land. The sediment, besides gradually filling the lake, inhibits the penetration of light into the water. Apparently, it is because of this lack of light that algal blooms have not appeared. Bacterial contamination of the lake to levels above those considered safe for swimming was noted after one large storm. Since no septic tanks are present in the basin, and no sewer overflows were noted, it is probable that street runoff was the source of contamination. Small amounts of DDT-family compounds were found in the lake sediments.

The water budget of Lake Sallie in Minnesota is being determined as part of a research project to develop methods and techniques for control of accelerated eutrophication. Preliminary surface-water and ground-water data, analyzed by W. B. Mann IV and M. S. McBride for the 1970 water year, indicated that surface-water inflow to Lake Sallie was 14,200 acre-ft and outflow was 15,700 acre-ft. Evaporation, estimated from available climatic records, was 3,000 acre-ft, and direct precipitation on the lake surface was 2,100 acre-ft. The net gain was 2,400 acre-ft for the water year, or an average of approximately 3.3 cfs seepage from ground water, including seepage in the area around the dam between Lake Sallie and neighboring Muskrat Lake. Particular attention was paid to the details of the local ground-water flow systems. The lake receives some water from regional flow systems by way of deeply-buried drift aquifers, but most comes from a surficial outwash which contains water under water-table conditions. The inflow from the water table is strongly localized by hills in the till that underlies the outwash.

WATER USE

Water use in the United States in 1970

C. R. Murray reported that the district water-resources offices of the U.S. Geological Survey were requested to make estimates of water withdrawals, consumption, conveyance losses, and other factors affecting the use of water in 1970 for public supplies, rural use, irrigation, hydroelectric power, public-utility thermoelectric power generation, and self-supplied industrial purposes. Estimates were also requested as to the source of the water withdrawn, whether from ground water, surface water, or reclaimed sewage. The water used was to be classified as to its quality, whether fresh or saline.

Water use was reported on the basis of the 217 subregions in the United States established by the Water Resources Council. The subregions together form 21 major water-resources regions, but when subdivided so as to follow State boundaries they form 370 reporting units. Compilation of data also is carried out for the 50 States, the District of Columbia, and Puerto Rico. Water-use reports have been received from Nebraska, Texas, Louisiana, Alaska, New Jersey, Maryland, and the District of Columbia. Data-processing techniques have been set up to tabulate the information by the end of the calendar year.

Two studies relating to the sources of water-use data in the United States were started in fiscal year 1971. These studies are primarily concerned with State and local governmental sources of water-use data. The district offices compiled a list of sources for the Office of Water Data Coordination (OWDC) of the Geological Survey. This information, along with data being obtained under contract by Enviro-Control, Inc., will be incorporated into the OWDC data network.

Estimates of ground-water use in the San Joaquin Valley, Calif.

Municipal and agricultural ground water pumped annually is being estimated by William Ogilbee (r0259) and H. T. Mitten on a continuing basis in the San Joaquin Valley, Calif. Estimated municipal pumpage is based on census figures, population projections, and pumpages reported by organizations supplying water to communities. Estimated agricultural pumpage for unit areas of 9 sq mi is based on electrical power used, natural-gas consumption, plant-efficiency tests, and water-level data.

Ground-water withdrawals from the Floridan aquifer, middle Peace and upper Alafia River basins, Florida

A. F. Robertson reported that ground-water withdrawals for public supplies by municipalities in and immediately adjacent to the study area (950 sq mi) totaled 28.4 mgd during 1970. About 20 percent of the citrus acreage in the study area has been inventoried for ground-water withdrawals. From available data, it was estimated that 50 mgd was pumped for citrus irrigation in the total area being studied.

Determination of withdrawals for industrial use, including phosphate mining, has not been completed but is expected to be at least 200 mgd.

Water-use data system devised for Georgia

A. M. F. Johnson reported that techniques and forms similar to those developed for the Tennessee Division of Water Resources were adapted for use in determining water use in Georgia for 1970. Information collected includes source of the water, purpose of use, and disposition of waste water. Major water users include about 6,000 manufacturers, about 2,000 large agricultural water users, and about 2,500 municipal water distribution systems.

Ground-water pumpage from the Snake Plain aquifer, southeastern Idaho

A study by H. W. Young and W. A. Harenberg to determine ground-water pumpage from the Snake Plain aquifer, the largest yielding aquifer in Idaho, showed that 1,059,000 acre-ft was pumped in 1969 for irrigation, municipal, industrial, and rural-domestic needs. Pumpage for irrigation alone amounted to 980,000 acre-ft.

Ground-water capabilities of mid-Arkansas River basin, Kansas and Oklahoma

S. W. Fader and R. B. Morton found that total ground-water withdrawals can be increased from wells in alluvium of the Arkansas River valley between Great Bend, Kans., and the Kansas-Oklahoma State line. Present withdrawals of about 250,000 acre-ft per yr are less than 15 percent of the average annual recharge to the alluvium. However, an anticipated sevenfold increase in ground-water use for irrigation by year 2000 probably will cause significant water-level declines or streamflow depletion.

Ground-water development possibilities in Haskell and Gray Counties, Kans.

Large quantities of ground water suitable for irrigation are available from wells in alluvium of Pliocene and Pleistocene age in Haskell and Gray Counties, Kans., according to E. D. Gutentag, L. E. Stullken, H. E. McGovern, and W. A. Long. Well yields are as great as 2,500 gpm, and as much as 25 million acre-ft of recoverable ground water may be stored in the alluvium underlying Haskell County alone. In 1970, it was estimated that 400,000 acre-ft of ground water was withdrawn by 1,100 irrigation wells. Withdrawals for irrigation have caused about 10 feet of water-level decline since 1940, but this decline is less than 10 percent of the average saturated thickness of the alluvial aquifer.

Public and industrial water use in Kentucky

A recently completed inventory of public and industrial water supplies in Kentucky indicated that an average of about 612 mgd was used in 1968–69. This was an increase of 29 percent in 10 yr. The inventory, conducted by D. S. Mull, T. W. Lambert, and R. V. Cushman,[82] included all public water supplies and those industrial supplies withdrawing more than 25,000 gpd. Public supplies used about 31 percent and industrial supplies about 69 percent of the total water used. The average per capita use of water furnished by municipal and utility water districts for domestic supply was 86.5 gpd, about 84.5 percent being supplied from surface-water sources and 15.5 percent from ground-water sources. The yield from ground-water sources ranged from 5 to 9,000 gpm. The average daily use by industry was about 423 mgd, which represents an increase of about 32 percent in the 10-yr period.

Lowering of water table in irrigated section of Holt County, Nebr.

C. F. Keech reported that the water table in the Atkinson-O'Neill area, Holt County, Nebr., is lowering as much as 2 feet per yr owing to the large increase in pumpage for irrigation during recent years. As a result, well yields are declining from their earlier average of about 650 gpm. Adding to the problem is the reduction in well yields, particularly at the height of the irrigation season, caused by the mutual interference between pumped wells. During 1970, 54 new irrigation wells were drilled, increasing the total to about 625. Withdrawals during a season of near-average climatic conditions now average approximately 50,000 acre-ft. The water-yielding sediments consist of Pleistocene and Pliocene continental deposits. Those of Pleistocene age are mostly sandy gravel and range in thickness from a few feet to 100 feet, and those of Pliocene age (the Ogallala Formation) are silt, silty sand, and sandstone and range in thickness from 150 to 250 feet.

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[82] Mull, D. S., Cushman, R. V., and Lambert, T. W., 1971, Public and industrial water supplies of Kentucky, 1968–69: Kentucky Geol. Survey Inf. Circ. [In press]

Estimated water use in Nevada

Estimates of water use in Nevada made by J. R. Harrill for the period 1950–69 indicated that withdrawal has increased from about 4.1 million acre-ft in 1950 to about 4.6 million acre-ft in 1969. Diversion of streamflow has increased from 3.9 million acre-ft to 4.0 million acre-ft during the period, whereas use of ground water (pumpage and spring flow) has increased from 170,000 to 600,000 acre-ft. Pumpage from wells has shown the largest increase, from about 53,000 acre-ft in 1950 to about 490,000 acre-ft in 1969. During 1969, 3.3 million acre-ft, or about 70 percent of the total water used in the State, was for irrigation.

INTERNATIONAL HYDROLOGICAL DECADE, 1965–74

The U.S. Geological Survey continued its participation in the 10-yr program of cooperative international studies in scientific hydrology known as the International Hydrological Decade (IHD). The network of 87 river stations for observing and recording streamflow, chemical quality, and suspended-sediment load was maintained. This network provides a general index of the discharge of surface water and of dissolved and suspended material from the continent to the oceans. Observations were continued at 23 lake and reservoir stations and at selected wells; these stations furnished data on the chemical quality of lake and reservoir waters, ground water, and on water levels.

Hydrologic benchmarks, established at 57 localities, provide information on natural hydrologic conditions largely removed from the effects of man's activities. Measurements of the tritium content of water in the 20 principal rivers in the United States, and of precipitation at 16 localities, are being used to evaluate the effect of precipitation on the chemical character of inland waters.

Hydrologists of the Geological Survey participated in international symposia, seminars, meetings of working groups, intercountry exchange of experts, discussions of selected activities chosen for particular years, and hydrologic research at selected areas in the United States, where the results are expected to have international application. A discussion of some of the activities follows.

E. L. Hendricks, United States delegate, and R. L. Nace, member of the United States delegation, participated in a meeting of the Coordinating Council for the IHD in Geneva, Switzerland.

A symposium on world water balance, sponsored by the United Nations Educational, Scientific, and Cultural Organization (UNESCO) as an activity of the IHD, and by the World Meteorological Organization and the International Association of Scientific Hydrology, was held in Reading, England, and attended by E. L. Hendricks, R. L. Nace, and T. E. A. van Hylckama. Nace (r2454) delivered the keynote address on the status and prospects of world hydrology, and van Hylckama (r1802) presented a paper on the effect of water on the balance of the earth.

M. E. Moss served as codirector responsible for surface-water aspects of the Regional Seminar on the Hydrology of Droughts, held in Lima, Peru, and sponsored by UNESCO, the Peruvian National Committee for the IHD, the Chilean National Committee for the IHD, the National Agricultural University at La Molina, Peru, and the University of Chile. Moss presented five lectures on various topics, including surface-water hydrology, operations research, and drought problems.

G. F. Smoot coordinated the United States participation in a symposium of hydrometry held in Koblenz, West Germany. The symposium was organized within the framework of the IHD and sponsored jointly by UNESCO, the World Meterological Organization, the International Association of Scientific Hydrology, and the National Committee for the IHD of the Federal Republic of Germany.

R. F. Hadley served as United States coordinator of the mid-Decade International Symposium, Results of Research on Representative and Experimental Basins, held in Wellington, New Zealand. Hadley presented a proposal for a global environmental monitoring network involving international organizations using the data being collected in representative and experimental basins.

Allen Sinnott, as a consultant for UNESCO in Nigeria, helped to evaluate the feasibility of establishing an institute of water resources to be supported initially by the Special Funds program of the United Nations Development Program.

As part of the program of the International Field Year for the Great Lakes (1972)—a joint contribution by the United States and Canada to the IHD—E. C. Rhodehamel began work on a network of hydrologic observations in the portion of Lake Ontario basin within the United States.

R. L. Nace continued his activities for the IHD as a member of the Working Group on Water Balances, of which he had served as chairman for the past 5 yr; Alfonso Wilson continued studies on the water balance of North America; and G. W. Whetstone continued work as co-editor in the preparation of a state-of-the-art report on "Systems for Acquisition, Transmission, and Processing of Hydrological Data" (SAPHYDATA), to be published by UNESCO.

R. L. Cory continued water-quality monitoring, and studies of the epifauna, in three small estuarine tributaries (South River, Rhode River, and West River) on the west side of Chesapeake Bay, in Anne Arundel County, Md.

Allen Sinnott and R. L. Nace continued bathymetry studies in the Rhode River estuary and collected samples of bottom sediments in representative parts of the estuary to provide guidance for coverage in more detail. The preliminary samples were processed in the hydrologic laboratory in Denver, Colo., for mechanical and mineralogical analysis.

H. E. Skibitzke, R. L. Howell, and M. L. Brown designed a waste-water monitoring system and central radar facility for Venice, Italy.

M. F. Meier, L. R. Mayo, and W. V. Tangborn monitored representative glaciers in Alaska and the Western States, and

A. S. Post continued studies of recent changes in glaciers on volcanoes in Alaska. W. J. Campbell and L. A. Rasmussen made studies of sea-ice movement in the Beaufort Sea.

J. K. Culbertson and W. F. Curtis prepared a report on suspended-sediment discharge to the sea from the shores of the conterminous United States.

MARINE GEOLOGY AND HYDROLOGY

MARINE AND COASTAL GEOLOGY

The continuing pressure of population growth and economic development imposes increasing demands on the Nation's resources. The requirements of a growing and urbanized population necessitate emphasis on obtaining new sources of fuel and other raw mineral resources. The relatively unexplored continental margins encompass over 1 million sq mi and contain 17,000 mi of adjacent shore on which 45 percent of the Nation's population live. The continental margins are becoming increasingly important as a potential source of much of the Nation's needs. Knowledge of the geology, mineral resources, and related geologic environments on our adjacent shelves is urgently needed in order to optimize the multiple use of the sea floor, and to preserve the coastal marine environments, as well as to keep pace with the rising demands of mineral and fuel requirements of the Nation. To evaluate the submerged continental margins, the U.S. Geological Survey is conducting extensive investigations to meet these increasing demands of the Nation. An initial program of reconnaissance marine geological and geophysical investigations and mapping of our submerged continental margins has been underway since 1962. The principal aims of these systematic investigations are directed toward the identification and appraisal of potential mineral and fuel resources, evaluation of the geologic hazards adjacent to populated coastal zones, investigation of the origin and geologic history of the continental margins, and studies of the geologic processes in the marine environment. Such detailed systematic investigations of our continental margins will significantly aid in the future development of our Nation.

The U.S. Geological Survey (USGS) is continuing diversified geologic investigations in many areas to explore the Nation's surrounding marine environment. Studies are being conducted on the Atlantic, Gulf of Mexico, Pacific, and Alaskan continental margins and in the Caribbean Sea. Many of these investigations involve cooperative arrangements with other Federal agencies such as the Coast Guard, Naval Oceanographic Office, and National Oceanic and Atmospheric Agency. Other investigations are being conducted under research contracts with universities and oceanographic institutions. Results of the past year's research programs in marine geology are summarized in the following paragraphs.

NORTH ATLANTIC AND ATLANTIC CONTINENTAL MARGIN

A comprehensive study of sedimentological and geophysical data from the Atlantic continental margin defines the geologic framework, sedimentological provenances, and mineral resources of the continental shelf. Geologic investigations include detailed studies in the Gulf of Maine to determine bedrock geology, structure, sea-level changes, glacial history, and to locate deposits of sand and gravel. Studies on the southern shelf are directed toward determining sedimentological processes that affect relict sediments, source and mineralogic composition of sediments, and geologic history of the shelf. Joint investigations are conducted with Woods Hole Oceanographic Institution (WHOI) and Duke University under research contract.

Coccolith zonation in the North Atlantic

J. D. Bukry reports that deep-ocean cores from the North Atlantic at lat 45° N. to lat 60° N. contain post-Eocene fossil coccolith floras that differ from coeval tropical floras in that species of *Discoaster*, *Sphenolithus*, and *Triquetrorhabdulus*, generally used for zonation, are rare or absent. The total number of species is smaller, and cosmopolitan species dominate. As these cosmopolitan species can be employed to zone high-latitude samples, the cold-water floras illustrate the utility of biostratigraphic zones recognized by the entire set of species present, in contrast to zones based on the last or first occurrence of single species which may be restricted to tropic or subtropic areas. Through identification of the entire flora, cores from high latitudes can be correlated with standard low-latitude zones, with only slight loss of precision, through the use of cosmopolitan taxa.

Geophysical investigations of the Gulf of Maine

R. N. Oldale (USGS), and B. E. Tucholke and C. D. Hollister (WHOI) report that continuous seismic profiles off eastern Massachusetts define basins filled with as much as 40 m of late Pleistocene-Holocene silt and clay. These deposits formed during the postglacial rise in sea level when lake and oceanic water filled depressions formerly occupied by ice lobes. Bottom currents have reworked offshore topographic highs consisting of glacial drift, inferred to be as much as 200 m thick, into sand and gravel deposits of unknown thickness. An acoustic basement, probably of crystalline metasedimentary rock, extends from sea-floor outcrops to approximately 300 m below the sea floor. A sedimentary sequence of probable Cretaceous or Tertiary age overlies the acoustic basement to the east (Stellwagen basin–Jeffrey ledge). An oval-shaped basin in Nantucket Sound containing several kilometers of sediment (inferred to be Carboniferous-Triassic age) is cut off to the east by a north-trending fault.

In deep sonic profiles off eastern Massachusetts Elazar

Uchupi and K. E. Prada (WHOI), and R. N. Oldale (USGS) identified four main acoustical units within the sediment. These units are coastal plain sediments of Cretaceous-Tertiary age overlying a basement of Paleozoic and Triassic rocks, glacial drift of Pleistocene age, glaciolacustrine deposits of late Pleistocene age, and glaciomarine deposits of late Pleistocene-Holocene age. The glacial and lacustrine deposits define stages in the last retreat of the glaciers from coastal New England. A fluvial drainage system excavated the Gulf of Maine during the late Tertiary or early Pleistocene. The drainage system shaped cuestas and carved out valleys along the northern edge of Georges Bank.

Sediment types in western Gulf of Maine

J. S. Schlee (USGS), and D. W. Folger and Charles O'Hara (WHOI) have analyzed several hundred sediment samples collected from the western Gulf of Maine. Sea-floor sediments in this area are related to the physiography. Sand and gravel occur on topographic highs, whereas silty clay occurs in basins. The content of organic carbon, which is most abundant in the fine-grained sediment, is low (less than 2.5 percent). Carbonate occurs as shell detritus and is most abundant (less than 5 percent) on the flanks of the topographic highs.

Fauna on the middle Atlantic shelf

J. E. Hazel and P. C. Valentine compared ostracodes collected under the joint WHOI-USGS cruises to the Atlantic continental margin with the assemblages of the Yorktown (upper Miocene–lower Pleistocene) and Norfolk formations (Sangamon). Utilizing the living species found in these formations, Hazel and Valentine were able to infer that the marine climate had changed from mild temperate to warm temperate and finally to subtropical during the deposition of the Yorktown Formation. Warm temperate conditions returned during Norfolk time. During most of the last several million years, a more equable climate than now prevailed along the middle Atlantic coast.

Pyrite cementation on the lower continental rise

M. E. Field and O. H. Pilkey (both of Duke University) discovered pyrite-cemented terrigenous silty sand layers ½ cm thick in four piston cores from the lower continental rise (4,770–4,950 m) off North Carolina. In thin section, large euhedral crystals of pyrite seem to have grown at the expense of carbonate in the rock. Turbidity currents probably transported and deposited the organically rich, fine-grained continental slope and shelf sediments in rapid pulses. The organically rich, fine-grained sediment may have generated the sulfide which crystallized in the silty sand layers.

Bottom features in Onslow Bay, N.C.

In Onslow Bay, N.C., I. G. Macintyre and O. H. Pilkey (both of Duke University) using a "swimmer sled", have mapped and sampled several north-south-trending bands of coarse calcareous debris (mollusks, oolites, Foraminifera, barnacles) in slightly depressed 20-m-wide channels at a depth of 18 m. These bands are 60 to 100 m apart and cross areas of finer, less calcareous sand. Two explanations are considered for the origin of the calcareous bands: (1) they represent areas of winnowing by channeling bottom currents produced during storm surge reflux, or (2) fine nearshore "equilibrium" sediments may be transgressing over coarser relict shelf sediments.

Investigations along the southern margin

J. B. Judd, W. C. Smith, and O. H. Pilkey (all of Duke University) have shown statistical differences in the percentages of iron oxide stained grains of two sand-size fractions from shelf, beach, and river samples between Cape Hatteras, N.C., and Cape Kennedy, Fla. More iron oxide stained quartz is present in streams draining the Piedmont than in streams draining the coastal plain. The presence of these grains on the shelf and in concentrations adjacent to river mouths indicates a large contribution of this detritus to the shelf during the Pleistocene. Since the postglacial rise in sea level, extensive transportation of these relict sediments has not occurred.

O. H. Pilkey and B. D. Bornhold (Duke University) have examined shelf and shoreline samples for gold along North and South Carolina. The richest sample, collected off Cape Lookout, N.C., contained 6.9 ppb gold. Most of the samples north of central Onslow Bay, N.C., contain detectable gold in the heavy-mineral fractions. South of this area gold was not detected.

J. D. Milliman and D. A. Ross (WHOI), and O. H. Pilkey (Duke University) petrographically examined approximately 6,000 sediment samples from the southern Atlantic shelf. Sediments north of Cape Hatteras, N.C., are arkosic to subarkosic fluvial sands; quartz-rich fluvial sands cover much of the inner shelf south of Cape Hatteras. At present, sediment is accumulating only in estuaries and on the continental slope. The principal source of new detritus on the shelf is calcareous skeletal material.

GULF OF MEXICO AND CARIBBEAN SEA

Marine geologic studies in the Gulf of Mexico–Caribbean Sea region have resulted in significant new scientific findings. The studies included investigations of the tectonic evolution of salt-dome basins on the Texas shelf, sedimentological, mineralogical, and geochemical investigations in the Gulf of Mexico, extensive geophysical and sedimentological data gathering on the Virgin Island–Puerto Rico shelf, and the Tektite II project which involved three Geological Survey scientists living underwater for 20 days.

Cooperative studies were conducted jointly with the Virgin Islands government and with the Commonwealth of Puerto Rico. Other studies in the Gulf of Mexico have been conducted jointly under research contract with Texas A&M University (TAMU), Louisiana State University (LSU), Woods Hole Oceanographic Institution (WHOI), and with personnel from the University of Texas (UT).

Coastal current pattern, southern Texas

Coastal current patterns studied by R. E. Hunter and G. W. Hill along the south Texas coast north of the Rio Grande suggest that the principal movement of bottom water is not always in the same direction as that of the surface water. In the spring and the summer months air-dropped drift bottles moved northwest in the offshore areas and northerly in the littoral zone, whereas seabed drifters concurrently moved southward along the bottom apparently in the extension of a tongue of rapid drift located 10 to 20 mi offshore.

Sedimentological studies of Laguna Madre, Tex.

Sedimentological investigations by K. A. Dickinson and G. W. Hill show that sediments of northern Laguna Madre, Tex., average 74 percent sand, 19 percent shell material, and 7 percent clay. Although the sediments have been disturbed in Laguna Madre by dredging of the intracoastal canal, certain depositional patterns emerge outside the disturbed areas. Sand grain size is slightly coarser and shell material is more abundant near the mainland shore. Clay is more abundant near the barrier island shore. This grain-size distribution reflects the energy regimen in the lagoon. The predominant wind blows from the southeast, producing large waves near the mainland shore and smaller waves to the lee of the barrier island. The finer clastic material is deposited in the area of lowest energy near the barrier island shore.

Geochemical studies in Baffin Bay, Tex.

Sediment samples from Baffin Bay, Tex. were analyzed by C. W. Holmes for "nondetrital" uranium and thorium. Baffin Bay is a restricted shallow bay on the southern Texas coast. It is isolated from the Gulf of Mexico by an extensive barrier island, Padre Island. The only water exchange into the bay is through Laguna Madre. Because of its restricted nature, the waters of the bay are highly saline throughout much of the year. Clays high in hydrogen sulfide content and barren of Foraminifera are present in the central part of the bay; sands are found on the margin. The "nondetrital" uranium and thorium content of the sediments from the central portion of the bay range between 1 and 8 ppm. The highest values are near the mouths of ephemeral streams entering the bay. The similar distribution of uranium and thorium indicate that uranium is reduced on entering the bay. In this reduced chemical state, uranium, like thorium, forms an insoluble hydroxide and is precipitated. Isotopic analysis of uranium reveals the average U^{234}/U^{238} ratio to be 1:20, indicating a radioactive disequilibrium of 20 percent. This suggests that U^{234} is more mobile than U^{238} and less likely to precipitate upon entering the marine environment.

Geophysical investigations of the Gulf of Mexico

L. E. Garrison and H. L. Berryhill, Jr., have interpreted the San Marcos arch to be a probable basement high which, trending southeastward from the Llano uplift toward the Texas coast, separates two salt dome basins.[83] The crest of the arch is marked in the subsurface by a thinning of overlying sedimentary units and by an absence of salt domes. Interpretation of seismic profiles from the continental shelf and slope suggests that the arch continues seaward under the slope in a region anomalously free of salt diapirs. The arch separates the Sigsbee Escarpment salt front into two segments which are related to the Gulf Coast salt basin and the Rio Grande salt basin, respectively.

Studies by R. G. Martin of acoustical profiles show the Gulf Coast geosyncline to extend eastward beneath the continental margin of northwest Florida. In this region it merges into the Apalachicola or southwest Georgia embayment and is separated from the south Florida basin by the Middle Ground arch.

Sedimentary structures in the Gulf of Mexico

X-ray radiographic studies by A. H. Bouma (TAMU) of cores obtained from the Gulf of Mexico by the USNS Kane have revealed sedimentary structures attributable to processes of cyclic sedimentation. The discovery of upper parts of the turbidite model in even the very fine-grained sediments of the western abyssal plain indicates that turbidite deposits extend from the toe of the Mississippi River delta to the western Gulf of Mexico.

Gravity study of the continental shelf off west Florida

H. L. Krivoy reports that accurate, detailed seaborne and land gravity data may provide a tool for the demarcation of areas underlain by continental crust from areas underlain by oceanic or transitional crust. Analysis of gross gravity patterns suggests that crustal blocks found in anomalous settings may be indicative of recent geotectonic history. Using this technique it may be possible to delineate and map deep and intermediate crustal structures which may, or may not, persist as surface expressions of geology or topography.

[83]Garrison, L. E. and Berryhill, H. L., Jr., 1970, Possible seaward extension of the San Marcos arch [abs.]: Geol. Soc. America Abs. with Programs, v. 2, no. 4, p. 285–286.

Tidal marsh sediments along northeast Gulf of Mexico

V. E. Swanson, A. H. Love, and I. C. Frost have completed investigations of modern sediments in a *Juncus* tidal marsh between the Aucilla and Suwannee Rivers in northwest Florida.[84] The characteristic peaty sandy mud contains 15 to 40 percent organic matter of the humic type that is composed of 75 percent decomposed particulate fragments and 25 percent flocculated organic acids. Eighty percent of this organic matter is derived from land plants and is transported to the Gulf of Mexico by river and creek waters; the organic material enters the Gulf of Mexico and is swept back by tidal currents and onshore waves into the tidal marsh where it is deposited. Twenty percent of the organic matter in the sediment is derived from semi-indigenous *Juncus* marsh grass and, to a minor extent, from offshore sea grasses such as *Thalassia*. Bitumen, which contains 24 percent hydrocarbons, makes up 0.5 percent of the total organic material. The clastic mineral fraction is more than 95 percent poorly sorted, silt- to medium sand-size quartz and siliceous spine and diatom fragments; only a few percent of clay minerals are present. Major diagenetic changes occur in the sediment at depths of less than 1 m. Typically, below 20 cm all calcium carbonate shell material is dissolved and removed; from the upper 10 cm to below 50 cm the alkaline-soluble humic material decreases from 25 to less than 10 percent of the total organic matter; and unstable amorphous iron sulfide forms 1 to 2 percent in the upper 20 cm of sediment, but more stable iron sulfide increases to form as much as 20 percent of silt-sized pyrite below 50 cm.

Suspended matter in the Gulf of Mexico

F. T. Manheim and J. C. Hathaway (USGS), and Elazar Uchupi (WHOI) have completed their study of suspended matter in the north and western Gulf of Mexico. The data confirm the progressive decrease in suspended matter away from shore and the concentration of mineralogenic suspended matter in the shelf waters. Organic aggregates containing variable amounts of mineral detritus were common and may be important in the settling of fine particulates to the sea floor at rates considerably faster than predicted by Stokes' law.

Minerals in Gulf of Mexico sediments

Studies by J. P. Morgan, G. F. Hart, S. B. Devine, and R. E. Ferrell (all of LSU) show that the minerals calcite, illite, smectite, quartz, kaolinite, and chlorite constitute the bottom sediments at depths greater than 200 m in the Gulf of Mexico. Calcite content decreases away from the Campeche Banks, whereas quartz shows the opposite trend. The distribution patterns of kaolinite, chlorite, and smectite divide the basin into eastern and western areas in which those minerals are relatively more abundant than in the central area. Illite is relatively more abundant in several lobes around the margin of the deep gulf.

Sediment movement off southwest Puerto Rico

Bottom sediments studied by L. E. Garrison off the southwest coast of Puerto Rico are concentrated into "sand waves" which are migrating slowly westward under the influence of strong coastal currents. Aerial photos show these sand bodies, which are oriented normal to the current along the coast east of Cabo Rojo, to lose their identity where the currents sweep to the northwest around the cape. The sediments ultimately come to rest in the relatively shallow waters west of Cabo Rojo where they are being stabilized by marine plant growth.

Guayanilla canyon system, Puerto Rico

A dendritic pattern of submarine canyons, called the Guayanilla canyon system, was mapped by L. E. Garrison and J. V. Trumbull off the southwest coast of Puerto Rico. The alinement of the present drainage system on the southwest part of the island with drowned embayments, shelf channels, and branching submarine canyons suggests a subaerial origin for the upper part of the canyon system. Seismic profiling in the upper canyon has defined three rock units separated by unconformities. Rock samples dredged from the canyon suggest that the canyons were eroded after early Miocene.

Investigations on the southern Virgin Islands shelf

L. E. Garrison and C. W. Holmes report that the mapped areal distribution of major sediment types on the insular shelf south of St. Thomas and St. John delineates sand deposits extending from the shore to 5.6 km seaward. The sand deposits, which are in an average water depth of 27 m, are greater than 1.2 m thick and cover approximately 90.7 sq km of the shelf. This represents approximately 11×10^7 m^3 of sand. Compositionally the sand averages 94.5 percent carbonate, 1.5 percent detritus, and 4 percent organic material. Seaward of the sand the predominant sediment type is algal(?) nodules. The nodules range in size from a few millimeters to about 0.5 m in diameter. The sand appears to be derived from the destruction of the algal nodules.

Continuous seismic profiling on the shelf south of St. John defines two buried bedrock ridges trending northeastward. They are believed to mark the crest of plutons similar to or connected with the larger Virgin Islands pluton to the north.

Tektite II, St. John, V.I.

U.S. Geological Survey participation in Man-in-the-Sea Project Tektite II consisted of two phases. In the first phase, H. E. Clifton and R. E. Hunter spent 20 days at a depth of 12 m in

[84] Swanson, V. E., 1971, Geochemistry and diagenesis of tidal marsh sediment, northeastern Gulf of Mexico: U.S. Geol. Survey Bull. 1360. [In press]

the Tektite habitat on the south side of St. John studying rates and effects of bioturbation. Experimental studies demonstrated that surficial structures such as ripple marks persist at most for about 6 weeks in an area of active bioturbation. Laminations in the upper centimeter of sediment are also quickly destroyed by organic stirring. Organisms also undermine pebbles and cobbles resting on the sediment surface, a process that leads ultimately to their burial. The rate and style of bioturbation differs depending on the environmental setting; burrowing fauna living in relatively fine sand modify the sediment surface more than do the crawling organisms that prevail over coarser sand. Crawling organisms, however, tend to destroy lamination near the surface more quickly.

In the second 20-day phase, R. L. Phillips (USGS) and D. W. Bowman (UT) investigated the nearshore sea-level history of St. John to depths of 25 m. Two relict shorelines are identified, at depths of 7 to 8 m and at 12 to 14 m below the present mean sea level. The shorelines are identified by cemented beachrock conglomerates paralleling the present shoreline, by areas of anomalous concentrations of well-rounded noncarbonate cobbles and boulders on carbonate sand flats, and by erosional platforms cut into the bedrock on St. John.

PACIFIC CONTINENTAL MARGIN

Diversified investigations of marine geology along the Pacific continental margin continue in an effort to determine the geologic structures of the continental shelf and slope, evaluate the economic potential of the shelf, and recognize geologic hazards adjacent to population centers on the coastline. Cooperative investigations are conducted with the U.S. Navy Undersea Research and Development Center (USNUC), the Water Resources Agency of the State of California, and the U.S. Atomic Energy Commission. Other work is conducted with the University of Washington, Oregon State University (OSU), University of Southern California, and Scripps Institution of Oceanography (SIO) under research contract to the U.S. Geological Survey. Also participating in investigations are Stanford University, San Jose State College (SJSC), San Francisco Bay Toll Crossing Authority, Bay Conservation and Development Commission, and the U.S. Department of Housing and Urban Development.

Geophysical investigations off central Oregon

P. D. Snavely, Jr., and N. S. MacLeod have made a preliminary interpretation of geophysical data collected during the USGS–USNUC cruise of the USNS *Bartlett* offshore from Oregon and Washington. Seismic reflection profiles, using the USGS 165-kj sparker source, and magnetic profiles were made along 1,600 km of track extending from near Cape Blanco, Oreg., to Port Angeles, Wash. A part of this cruise included four crossings of the continental shelf and slope and the eastern border of the Cascadia plain off the central part of the Oregon coast.

The acoustic basement west of the shelf and slope is virtually flat; adjacent to the base of the slope it dips 1° to 2° towards the continent, but sediments above basement dip progressively less, and the youngest sediments are practically horizontal. The sediments that overlie basement comprise two sedimentary units separated by a disconformity that total 2,000 to 3,000 m; the older unit thickens towards the base of the slope. These two sedimentary units have acoustic characteristics which suggest they are turbidites. Near lat 45° N., the contact between the base of the continental slope and the abyssal plain appears to be a fault, whereas at 44° 30′ N., sediments on the abyssal plain continue on to the lower continental slope where they are folded and faulted.

The continental slope near lat 45° N. is underlain by folded and faulted sedimentary rocks that may be older (Miocene?) continental rise deposits. Troughs on the continental slope are filled by as much as 1,000 m of bedded sedimentary rocks that form two units separated by an unconformity. The upper unit is flat lying, but the lower unit progressively increases in dip to the east with increasing depth.

Sedimentary rocks on the outer continental shelf are strongly to gently folded; however, deformation progressively decreases towards land. In the central part of the shelf, some folds have "ruptured" cores and are probably siltstone diapirs. In places, these folds form topographic highs on the sea floor and involve sediment at least as young as late Pleistocene. The inner shelf sediments are gently folded, faulted, and truncated by a late Miocene unconformity. The sedimentary rocks of the inner shelf can be traced on acoustic profiles to the Oregon coast where they can be correlated with the onland geology.

Investigations along the Oregon continental margin

Sedimentological and foraminiferal evidence as reported by L. D. Kulm (OSU) strongly supports the hypothesis that abyssal plain sediments have been scraped off the oceanic plate west of Oregon and incorporated into the continental margin. Sandstone and siltstone from the lower continental slope off Newport have characteristics similar to those of Cascadia Basin turbidites and contain uniquely abyssal Foraminifera. The component of vertical uplift since deposition is approximately 1,000 m. In addition to the vertical motion, mineralogic evidence suggests that the sediments moved northward on the order of 200 km since their deposition. The heavy-mineral suite has very strong affinities with the Klamath Mountains provenance of northern California and southern Oregon and not with the Columbia River mineral suite that dominates off Newport today. Routes of sediment transport cannot be used to explain the observed relationships. The age of the sediments is probably Pliocene. All evidence indicates that the sea floor off Oregon has moved northward and to some extent eastward with respect to the adjacent continent since the Pliocene.

Marine terraces along the southern Oregon coast

Nearshore marine sediments on the highest of four coastal terraces being studied by R. J. Janda near Port Orford, Oreg., contain molds of a large distinctive pelecypod, identified by W. O. Addicott as *Clinocardium meekianum* (Gabb). Initial investigations suggested a lower Pleistocene age for the terraces, but *Clinocardium meekianum* (Gabb) has previously been found in strata of no younger than late Pliocene age. The high terrace sediments are, therefore, older than the highly fossiliferous lower Pleistocene strata exposed in the sea cliffs below a surfcut platform of a late Pleistocene terrace near the mouth of the Elk River. The lower Pleistocene strata contain pelecypods of a newly recognized *Clinocardium* species that is descendent from *C. meekianum.*

Oregon-California black sands

Examination of sedimentary structures by H. E. Clifton, R. E. Hunter, and R. L. Phillips in contemporary longshore bar-rip channel systems and in the mouths of streams along the coast of southern Oregon identifies the depositional processes active within these systems and provides criteria for their recognition in the stratigraphic record. Both systems are complications imposed on the topographically simple nearshore; laterally they grade into previously recognized structural facies of the uncomplicated nearshore. The primary structures of the longshore bar-rip channel system include horizontal stratification and landward-dipping cross beds on the bar, cross strata with longshore dips in the trough behind the bar, and seaward-dipping cross beds in the rip channels through the bar. Within stream mouths, cross strata generated by tidal currents are common. Their orientation and abundance depend upon stream discharge and gradient. Large-scale cross stratification exists in barred streams which are filled laterally by berm overwash or by windblown sand.

Investigations on the Oregon-California continental slope

Concurrently with a conventional air-gun profile, a detailed subbottom-reflection profile was obtained by E. A. Silver across the continental slope off the Oregon-California border using a 3.5 kHz profiler on a "fish" towed 50 to 75 m above the bottom. The deep-tow "fish" was developed by the Marine Physical Laboratory of Scripps Institution of Oceanography. Both profiles show a broad ridge 5 km wide above the base of the continental slope with slump blocks on the landward flank of the ridge and a low terrace 1 km wide at the slope base. The deep-tow profile provided a clearer definition of the slump blocks on the landward flank of the ridge, and also show slump blocks on the seaward flank. The air-gun record shows hyperbolic echoes on the steeper flank which obliterate the slump structures there and are superimposed over the terrace. Despite these differences in detail, a close correspondence of tectonically formed structures is seen on both the deep-tow and surface air-gun profiles and allows considerable confidence to be placed in regional tectonic interpretations based on conventional sea-surface reflection-profiling data.

San Francisco Bay

Mercury in surface sediment samples from the San Francisco Bay estuary, as reported by D. S. McCulloch (r 2326), D. H. Peterson, T. J. Conomos, K. W. Leong, and P. R. Carlson, ranges from 0.02 to 2.0 ppm (by weight of dry sediment). One higher value was determined as 6.4 ppm. The median concentration is 0.20 ppm; 70 percent of the analyses lie between 0.08 and 0.52 ppm. The mercury content of the sediment varies with respect to the source and hydraulic environment. Sediment in tributaries at the bay margin contains the highest concentrations (median 0.42 ppm, 70 percent range 0.17–0.70 ppm). Silt and clay in shoal areas have intermediate concentrations (median 0.17 ppm, 70 percent range 0.10–0.32 ppm), and sediment in the channels, where sand is most abundant and tidal currents are strongest, contains the lowest concentration (median 0.13 ppm, 70 percent range 0.06–0.23 ppm). The San Francisco Bay estuary is composed of four large interconnected bays. Sediment from the northern reach (Suisun and San Pablo Bays) has a low median concentration but shows the greatest range. A smaller range and the highest median values occur in the southern reach (south San Francisco Bay). The central part of the estuary, the central bay, has the smallest concentration range and the lowest median value. The rates of mercury introduction and removal appear to be greater in the northern than in the southern reach.

Residual drift on near-bottom waters in the San Francisco Bay estuary and the adjacent Pacific Ocean was studied by T. J. Conomos (r0062), D. H. Peterson, D. S. McCulloch, and P. R. Carlson between March 1970 and January 1971 by bimonthly releases of seabed drifters. Movement of drifters from the ocean into the estuary (2–4 km/day) is pronounced, and apparently bottom water moves toward the estuary within about 25 km of the bay entrances (Golden Gate). In the estuary, drifter movement is dominated by a perennial flow ($\approx$3 km/day) into the northern reach (San Pablo Bay) which has a large fresh-water inflow (Sacramento–San Joaquin Rivers) at its head. This landward drift converges with the seaward-flowing drift owing to river inflow ($\approx$1–2 km/day) in mid-San Pablo Bay. The estuary has a southern reach (south San Francisco Bay) which has no large fresh-water inflow at its head. The movement of drifters within this reach is slower (0.5–1 km/day) and reverses direction, apparently in response to density-induced circulation and wind.

Observed seasonal differences in behavior of nonconservative dissolved silica and conservative salinity were investigated by D. H. Peterson, T. J. Conomos, P. C. Doherty (all of USGS), and W. W. Broenkow (SJSC) and used to estimate rates of dissolved silica uptake by diatoms, the most abundant phytoplankton in the San Francisco Bay estuary. Preliminary results indicate typical uptake rates during the summer diatom bloom are about 0.1 mg/l day^{-1} SiO_2 (1.6 μg-atom/l day^{-1} Si) which is approximately 500 mg/m^2 day^{-1} SiO_2. Based on a silica-to-carbon utilization ratio of about 1 to 5 by weight, this corresponds to a carbon uptake of about 2.6 g/m^2 day^{-1}. Utilization rates greater than about 0.02 mg/l day^{-1} SiO_2 can be detected by the method used. Maximum rates integrated over a two-week period were about 0.4 mg/l day^{-1} SiO_2. Typical silica utilization rates apparently can exceed rates of silica supply to the estuary from the Sacramento–San Joaquin River system. During extended periods of low river inflow, the silica concentration in the estuary may become so low as to inhibit the growth rate of diatoms.

Aerial photographs of near-surface circulation patterns in San Francisco Bay and in situ measurements as determined by P. R. Carlson, D. H. Peterson, T. J. Conomos, and D. S. McCulloch (r0061) give a synoptic view of water and suspended particle movement. Tide-driven circulation in San Francisco Bay is modified by seasonal variations of fresh-water inflow and wind stress. During low summer inflow, water in the south bay is well mixed vertically and has a salinity similar to the adjacent Pacific Ocean. After the first major winter storm period, high fresh-water inflow lowers salinity and increases turbidity. Aerial photographs obtained concurrently with water measurements in the winter of 1970 demonstrated that a low-salinity, high-turbidity plume associated with the Sacramento River flowed southward and bifurcated. One lobe advanced more than 10 nautical miles south of the San Francisco–Oakland Bay bridge; the main lobe flowed seaward nearly 20 nautical miles to the Farallon Islands. In the south bay, salinity differences of 2‰ and light transmission differences of 15 percent were measured between the lobe and bay waters; ocean salinity differences of 7‰ and light transmission differences of 25 percent were measured between the ocean water and the main lobe. Aerial photographs, monthly cruise data, and bottom drifter data emphasize the importance of Sacramento–San Joaquin River inflow to circulation in and adjacent to San Francisco Bay.

Mapping by D. R. Nichols (r2166) and N. A. Wright of San Francisco Bay marshlands shows that in the past 120 years the size of the Bay has been reduced by 11 percent and the size of the marshlands by 60 percent. Deposition, either natural or man induced, and disposal of dredged waste have added 52 sq mi of new land; erosion and dredging have removed 3 sq mi of former marshland. The reduction of former marshland by filling and diking has restricted the tidal reach, which has increased deposition and scour of the mud flats and deposition in sloughs and channels.

Geologic investigations in Monterey Bay and Ventura basin, California

Joint investigations with the California Department of Water Resources were continued in Monterey Bay, central California, and conducted off Ventura, southern California, during 1970. Interpretation of the data from Monterey Bay by H. G. Greene (USGS) and J. S. Nelson (California State Department of Water Resources) was continued. Preliminary structural and geologic maps have been constructed as well as maps delineating areas where salt water may intrude fresh-water aquifers (H. G. Greene, r0042). The USGS R/V *Polaris* was used to gather geophysical data in both surveys, and Stanford University R/V *Proteus* was used to obtain geologic data in Monterey Bay. The basement rock in southern Monterey Bay consists of Mesozoic granodiorite that is continuous with the rock type located onshore at Point Pinos. Unconformably overlying the granodiorite is the Monterey Formation of Miocene age. Pliocene to Pleistocene sand and gravel, covered locally by the Salinas River deltaic deposits, overlie the Miocene strata. Areas where salt water may intrude fresh-water aquifers were located in the upper parts of the Monterey Canyon and on the offshore Salinas River delta. Active slumping within the Monterey Canyon is believed to expose aquifers to salt water. Slumping within the canyon is more extensive, of a larger scale, and probably more active than previously envisioned. A submersible dive by H. E. Clifton and H. G. Greene in Monterey Canyon located an outcrop of marine Pliocene siltstone on the southern wall of the canyon. Current structures were not observed in the canyon, suggesting that slumps are blocking the transport of sediment down the canyon. A fault zone, 3 km wide, trends N. 60° W. offshore from the town of Monterey. Several faults within this zone show surface displacement and are believed to be active and associated with recent seismic events in Monterey Bay.

In the Ventura basin more than 575 km of marine seismic profiles were obtained along a grid with a 1.7-km spacing between lines. Magnetic, bathymetric, and seismic high resolution (1-kj sparker) and intermediate (33-kj sparker) data were collected simultaneously during the survey. Preliminary examination by H. G. Greene, S. C. Wolf, and K. G. Blom indicates 1,000 to 1,500 m of Quaternary(?) silt, sand, and gravel is deposited offshore. Sedimentary strata containing fresh-water aquifers can be identified in the seismic records by their relationship to unconformities that are known to exist onshore. The fresh-water strata can be traced offshore for more than 5 km. The aquifers are exposed along the walls of submarine canyons and along the slopes of the Santa Monica and Santa Barbara basins. Seismic profiles across submarine canyons exhibit features that suggest some canyons have been buried and now are being exhumed; other canyons exhibit features characteristic of deposition rather than erosion. Mugu Canyon appears to have down-dropped fault blocks at its head, suggesting that it may be a fault-controlled canyon.

Submarine tufa along the Santa Cruz Island fault, California

G. W. Moore reports that calcitic tufa was dredged from a depth of 180 m by the R/V *Vantuna* from Footprint Reef (lat 33°57.2′ N., long 119°28.5′ W.), which lies off southern

California directly south of Anacapa Passage. The reef is within the Santa Monica–Santa Cruz Island fault zone at the southern boundary of the Transverse Range tectonic belt, and the tufa cements angular clasts of presumed Miocene age basalt that were derived from submarine outcrops. Quaternary tectonic activity along this fault zone is well documented by submarine fault scarps and historic earthquakes. The tufa is believed to be a secondary effect of tectonic activity associated with the Quaternary faulting.

Geophysical investigations, Santa Monica basin, southern California

Interpretation by H. C. Wagner and Arne Junger of acoustical reflection profiles suggests intermittent periods of tectonic activity, both south and north of the Santa Monica basin, and consequent sedimentation. The oldest (southernmost) Quaternary sediments were derived from a northwestern extension of the Santa Catalina Island ridge to the south and formed north-dipping terraces or fans. Rapid tectonic subsidence subsequent to the deposition of these sediments led to their being largely covered by a thick sequence of horizontally bedded basin-floor sediment. This basin-floor sediment was derived from a northern source and grades northward into slope and shelf sediments. These slope and shelf sediments interfinger with and are in part overlain by sediments containing deltaic forsets of an ancestral Los Angeles River that flowed westward into the eastern part of the Santa Monica basin.

ALASKAN CONTINENTAL MARGIN

Marine geologic investigations continue to reveal significant findings on the largest continental shelf area of the United States. A joint U.S. Geological Survey–National Oceanic and Atmospheric Agency study in the Bering Sea recognized positions of ancient valleys, drainage systems, glacial deposits, and ancient shorelines on the sea floor. The identification and location of these features will be of considerable value in the search for deposits of valuable detrital minerals on the sea bottom. Investigations conducted from the USNS *Bartlett* along the southern Bering shelf and continental margin located extensive sedimentary basins, defined structures on and adjacent to the continental shelf, and suggested processes whereby the continental margin evolved. The joint U.S. Geological Survey–U.S. Coast Guard study in the Chukchi Sea, conducted from the USCGS *Glacier*, delineated structural features as well as defined Tertiary or late Mesozoic sedimentary provinces. Studies were conducted jointly with the University of Washington (UW) and the University of Alaska under research contract to the U.S. Geological Survey, and in cooperation with the U.S. Navy Undersea Research and Development Center (USNUC), U.S. Coast Guard (USCG), and National Oceanic and Atmospheric Agency (NOAA).

North Pacific continental margin

R. E. von Huene reports that the continental slope of Alaska adjacent to the eastern Aleutian Trench is composed of thick deformed sedimentary rocks overlain and probably interbedded with large slump deposits and other products of mass wasting on the continent. Magnetic anomaly patterns indicate that the oceanic crust continues beneath the slope and continental terrace. Combined compressional deformation and major uplift formed the continental margin. Whether the deformational processes which resulted in the formation of the continental margin were continuous or intermittent cannot be determined. If coarse turbidites from the trench are incorporated into the continental slope by uplift, it is possible that new potential areas for hydrocarbon accumulation exist in the continental margin. Particularly interesting for future petroleum resources is the edge of the continental terrace where a large uplifted arch has been located;[85] however, the availability of source beds and reservoir sands is unknown.

Bering shelf investigations

Results reported by D. W. Scholl from the cruise of USNS *Bartlett* to the Aleutian Islands–Bering Sea region include discovery of a fault-controlled basin containing as much as 3 to 3.5 km of Cenozoic sediment southwest of St. Matthew Island, Bering shelf; a bowl-shaped basin of thick Cenozoic deposits beneath Amlia basin, Aleutian Ridge; a subsurface ridge, topped by diapiric structures connecting Bowers and Shirshov Ridges, south-central Bering Sea; extensive and thick (1 km or more) deposits of Cenozoic diatomites draping the continental margin and covering vast areas of Bowers and Shirshov Ridges; exposure of siliceous and argillaceous rocks similar to those found on many Aleutian Islands at depths of 2,000 to 3,000 m along the flanks of the ridge; a thick (1–1.5 km) and undeformed turbidite fill in the Aleutian Trench along most of its length, but an absence of the fill in the connecting Kamchatka Trench to the west; a very thick (3–5 km) sedimentary basin underlying Kamchatka Terrace and similar, but thinner (1–2 km), sequences of Cenozoic deposits beneath the Aleutian Terrace.

Nearshore investigations

P. W. Barnes and A. R. Tagg report that surficial marine sediments from southeastern Kuskokwim Bay near Goodnews Bay show scattered values of gold and platinum. Continuous high-resolution seismic profiling and precision bathymetric mapping coupled with postulated glacial movements suggest the existence of buried stream channels. These buried channels

[85]von Huene, R. E., and Shor, G. G., Jr., 1969, The structure and tectonic history of the eastern Aleutian Trench: Geol. Soc. America Bull., v. 80, p. 1889–1902.

may contain concentrations of gold and platinum. Offshore sediments consist of fine marine sands, relict gravels, and admixtures; the beaches are composed of coarse sands. This clastic assemblage is similar to that found elsewhere on the Bering shelf and reflects a minimal amount of shelf sedimentation since the last major rise in sea level.

Analyses for gold in beach sediments collected by Erk Reimnitz between Dry Bay and the western margin of the Copper River Delta extend the area of previously known marine gold accumulation. This investigation shows that some of the barrier islands of the Copper River Delta in the western part of this area compare favorably in gold values to beaches in the eastern part where mining operations have been active in the past. The volume of material containing gold seems to be higher on the barrier islands of the delta than that in the mining district. Relict gold placers may also occur in certain areas on the adjoining shelf.

Seward Peninsula

Studies by D. M. Hopkins and C. H. Nelson (USGS) and R. B. Perry (NOAA) of box cores, grab samples, seismic profiles, and a detailed bathymetric map provide the basis for dividing the Chirikov Basin of the northern Bering Sea into 10 physiographic provinces. Each province represents a region of similar topography that reflects a similar Quaternary history. The bottom topography has resulted largely from subaerial processes that operated when sea level was lower than present. Segments of a relict valley system can be discerned, which show that northern St. Lawrence Island, southern Seward Peninsula, and most of the intervening sea floor were once drained by a stream system that ran north through the Bering Strait to the Hope Sea Valley in the Chukchi Sea. A large lake occupied a tectonic depression in the sea floor north of the Kookooligit Mountains of St. Lawrence Island, and another large lake extended south from the entrance to Bering Strait.

A submerged delta of the Yukon River extends from near the present river mouth to approximately 20 km northwest of St. Lawrence Island. The ancient delta is believed to have formed during a temporary rise in sea level to about 25 m below the present sea level during an interstadial interval in the Wisconsin Glaciation. Other shoreline features, probably formed during the late Wisconsin–Holocene transgression, are found at depths of 38, 30, 24 to 20, 14, and 10 m.

Delineation of heavy-mineral provinces by Kolla Venkatarathnam (UW) on the northern Bering Sea floor results in a better understanding of Quaternary sediment dispersal and recent sedimentary history. Holocene silt and fine sand derived from the Yukon River dominate the region within 150 km of the delta and extend to St. Lawrence Island and east through the central Norton Sound. Relict fine sand derived from the Nome region of southern Seward Peninsula predominates nearshore to Golovin Bay on the east, north to Port Clarence, and southwest to within 100 km of St. Lawrence Island. Relict sand and gravel derived from the Cape Prince of Wales region of Seward Peninsula cover the region west of Port Clarence to the Bering Strait and south to central Chirikov Basin. Heavy minerals substantiate other data that indicate relict sand and gravel, derived from continental glaciers off Chukotka, extend over 100 km from Siberia to the eastern Bering Strait and southward nearly to St. Lawrence Island. Distinct sea-floor sediments derived from local Quaternary volcanic rocks occur within 50 km of north central St. Lawrence Island and off Stuart Island. Likewise, local bodies of igneous rocks of Northeast and Northwest Capes of St. Lawrence Island and Golovin Bay are traced as sources of nearby sea-floor sediments.

The heavy-mineral distribution substantiates the concept that much of the sand of the northern part of the Chirikov Basin was deposited during conditions of lowered sea levels. Higher concentrations of heavy minerals at depths of approximately 12, 20, and 30 to 34 m below the present sea level seem to reflect stillstands during recent sea-level transgression or regression.

Beaufort–Chukchi Sea Continental Shelf

Arthur Grantz (r0787) reports that the reconnaissance marine geologic survey of the Chukchi Sea by the U.S. Geological Survey and the U.S. Coast Guard, begun in 1969, was completed during September 1970. The Chukchi Sea lies west of Alaska's oil-, gas-, and coal-rich North Slope. The survey was conducted from the USCGC *Glacier* by a party of six USGS scientists and technicians, assisted by USCG marine science technicians.

The combined 1969–70 surveys of the Chukchi Sea include 55,000 sq mi of detailed geophysical reconnaissance based on track lines spaced approximately 20 mi apart, and 20,000 sq mi of broad-scale reconnaissance. The geophysical data include 4,850 mi of low frequency continuous seismic reflection profiles utilizing 120-kj and 160-kj sparker systems, 4,750 mi of magnetometer profiles, and about 1,000 mi of "high-resolution" continuous seismic reflection profiles utilizing a 1-kj sparker system.

The Hope basin of Cenozoic (and perhaps Cretaceous) sedimentary rocks, which was partly delineated in 1969, was found to underlie at least 45,000 sq mi of the southern and western Chukchi Sea. This basin is represented on the Alaska mainland by only a few small outcrops around Kotzebue Sound. The deep axial zone of the basin extends northwest from Kotzebue Sound to between Wrangel Island and the Siberian coast.

The Cretaceous sedimentary rocks and geologic structures of Alaska's North Slope were traced westward 200 mi across the shallow continental shelf that underlies the northern Chukchi Sea. The areal extent of these rocks was found to exceed 20,000 sq mi, but their full extent could not be determined because of the position of the Arctic ice pack in 1969 and 1970.

A large structural feature in the north-central Chukchi Sea was discovered and may be the western extension of the Barrow arch. Along the 169th meridian, this structure lies near the latitude of Point Barrow. This is far south of where it would be if projected in a straight line along its trend from its position in the Prudhoe Bay oil fields northwest through the Barrow area in northernmost Alaska. The structure is represented either by a northward-dipping monocline or by a broad asymmetric arch with a very gently dipping south flank and a more steeply dipping north flank. Bedded rocks, which buttress against the north flank of the monocline, are part of a broad tract of thick, almost flat-lying strata to the north. These flat-lying rocks were traced northward to lat 72°30′ N. Their age is unknown, but they may be Tertiary and (or) late Mesozoic; if so, they may represent a sedimentary province that is largely offshore along the north coast of Alaska.

Arctic coastal marine processes

Erk Reimnitz conducted investigations along the Beaufort Sea coastline in northern Alaska during the period of ice breakup. Where rivers discharge onto the ice-covered ocean very little river sediment remains on the ice to be rafted away from the arctic deltas. Much of the overflowing river water and sediment is flushed through large drain holes in the fast ice. Scour depressions occur in the sea floor beneath these drain holes in shallow water. Only in a narrow zone nearshore does the ice covered by river sediments melt in place. During the period of open water (August 15 to September 30) when ice covers the inner shelf, the grounding and plowing action of the ice extensively modifies the sea floor. This plowing action seems to be concentrated in the area between the outer coast barrier islands and the 10- to 15-m depth contour. Major linear topographic highs parallel to shore on the inner shelf, at a depth of 10 to 15 m, coincide with the boundary along which the inner pack ice is grounded.

OCEANIC AND INTERNATIONAL STUDIES

A part of the U.S. Geological Survey's marine program involves continuing research into the origin, evolution, and history of the continents, continental margins, ocean basins, and deep oceans. These studies encompass geophysical investigations and recent history of the Black Sea, comparative properties or differences of extruded submarine basalts off Mexico and Hawaii, and research into the evolution of the earth's crust.

Water content of submarine basalt

In a study of deep-sea pillow basalts dredged from the ocean floor, J. G. Moore (r0824) has found that vesicularity changes with composition as well as with depth. Alkalic basalts are more vesicular than tholeiitic basalts erupted at the same depth. The vesicularity data, when related to experimentally determined solubility of water in basalt, indicate that K-poor oceanic tholeiites originally contained about 0.25 percent water, Hawaiian tholeiites of intermediate K content, about 0.5 percent water, and alkali-rich basalts, about 0.9 percent water. Analyses of fresh basalt pillows show a systematic increase of H_2O^+ as the rocks become more alkalic. K-poor oceanic tholeiites contain 0.06 to 0.42 percent H_2O^+, Hawaiian tholeiites, 0.31 to 0.60 percent H_2O^+, and alkali-rich basalts 0.49 to 0.98 percent H_2O^+. The contents of K_2O, P_2O_5, F, and Cl increase directly with an increase in H_2O^+ content such that at 1.0 weight percent H_2O^+, K_2O is 1.58 percent, P_2O_5 is 0.55 percent, F is 0.07 percent, and Cl is 0.1 percent. The measured weight percentage of deuterium on the rim of one Hawaiian pillow is -6.0, relative to SMOW;[86] this value, which is similar to other indications of magmatic water, suggests that no appreciable sea water was absorbed by the pillow during or subsequent to eruption on the ocean floor.

Basalt dredged off west coast of Mexico

J. G. Moore reports that ocean-floor dredging and submarine photography in the Revillagigedo region off the west coast of Mexico reveal that the dominant exposed rock of the submarine part of the large island-forming volcanoes (Roca Partida and San Benedicto) is a uniform alkali pillow basalt; more siliceous rocks are exposed on the upper, subaerial parts of the volcanoes. Basalts dredged from smaller seamounts along the Clarion fracture zone south of the Revillagigedo Islands are tholeiitic pillow basalts. Pillows of alkali basalts are more vesicular than Hawaiian tholeiitic pillows collected from the same depths. This difference probably reflects a higher original volatile content of the alkali basalts.

Manganese-iron oxide nodules, common in several dredge hauls, generally contain nucleii of rhyolitic pumice or basalt pillow fragments. The pumice floated to its present site from subaerial eruptions, became waterlogged and sank, and was then coated with manganese-iron oxides. The thickness of palagonite rinds on the glassy pillow fragments is proportional to the thickness of manganese-iron oxide layers, and both are a measure of the age of the nodule. Both the oldest basalts (10–100 m.y.) and the youngest basalts (less than 1 m.y.) are along the Clarion fracture zone, whereas basalts from Roca Partida and San Benedicto volcanoes are of intermediate age.

Evolution of earth's crust

A. E. J. Engel (SIO) reports that studies of the nature and patterns of orogenic belts formed from the Holocene to the Precambrian suggest that the post-Permian sea-floor spreading coupled with fragmentation and widespread drift (greater than 1,000 km) of large segments (greater than 10^6 km^2) of continental crust are unique processes in the geological record.

[86] SMOW, standard mean ocean water.

Equally widespread drift of arcs and protocontinental segments may also have occurred in the Precambrian between 2.5 and 4 b.y. ago; but the Precambrian-type drift involved the agglomeration of evolving arcs and protocontinental segments into the one or, at most, two protocontinents which fragmented and dispersed in the post-Permian. During the Precambrian and Paleozoic, 2d-order fragmentation, fractionation, thickening, rotation, and subordinate drift of the evolving megacontinental masses definitely occurred in conjunction with orogenesis. The structural evidence for these conclusions is derived from studies of accordant tectonic patterns that result when the Americas, Africa, India, and Australia are reclustered into the pre-Triassic Gondwanaland, as defined by many independent lines of evidence. In this, megacontinent fold belts of both Paleozoic and Precambrian ages are juxtaposed into two coherent entities. The Precambrian fold belts defined by the conventional continental reclustering in the Permian comprise either a single or two subparallel orogenic systems of hemispheric dimensions which retained their interrelationships throughout the Precambrian and Paleozoic. The vast areas encompassed by concordant Precambrian fold fabrics over large segments of these megacontinental terranes suggest that the fold systems formed in response to a hemispheric, uniform force field in the earth's mantle between 2.5 and perhaps 4 b.y. ago.

Investigations in the Black Sea

The narrow southern and eastern shelves of the Black Sea exhibit faulting, slumping, and diapiric structures in continuous seismic profiles as reported by D. A. Ross and Elazar Uchupi (WHOI). The shelf and slope on the western part of the Black Sea are broad and may be depositional. Three distinct sedimentary units are correlated throughout the Black Sea basin. These consist of an upper unit, 30 cm thick, of microlaminated sediment composed of carbonate (coccolithophorids) and organic material; a middle unit, 40 cm thick, of organic material; and a lower unit of dark (organic) and light (carbonate) lutite. The stratigraphy in the basin relates to a succession of events; the lowest unit represents deposition from a fresh-water lake which changed 7,000 yr ago to a salt-water body (organic unit) and obtained maximum salinity 3,000 yr ago when the upper unit began to be deposited.

Appraisal of marine mineral resources

The second printing of the preliminary maps of the world subsea mineral resources[87] represents a thorough revision of the known distribution of evaporite basins in continental shelves, slopes, small oceanic basins, some parts of deep oceanic basins, and on the continents. The sea floor areas interpreted as locally favorable for petroleum were modified on the basis of recent marine geophysical findings, results of the Deep-Sea Drilling Project, and studies of sea-floor spreading. The newly recognized deep-sea areas with petroleum potential include sedimentary basins located on certain oceanic plateaus that are foundered crustal remnants left behind by continental drift, some abyssal areas that were downfaulted from preexisting shelves, and some of the Mesozoic sediments deposited in the relatively narrow, restricted "proto-ocean basins."

A report on the mineral resources of the sea (F. F. H. Wang, r2512) prepared in collaboration with the staff of the United Nations Secretariat was published in English, French, and Spanish. The report summarizes recent information relating to known and potential subsea mineral resources as well as developments of exploration and exploitation technologies. This study discusses critical problems relating to mineral resources development in the marine environment, recommends priority areas of engineering research, and suggests critical marine geology and geophysical investigations to be pursued by the industrialized countries of the world. These recommended areas of research are needed in order to overcome today's technological and economic limitations in marine mineral development and to improve our geologic knowledge on marine mineral resources.

ESTUARINE AND COASTAL HYDROLOGY

Numerical methods in estuarine hydrology

The complexities of circulation and mixing in estuarine waters can be approached through a variety of mathematical techniques. Several investigators reported numerical models that describe dispersion and flow in estuaries.

A mathematical model has been developed by H. B. Fischer to describe the highly stratified Duwamish River estuary of Washington. The model is designed to simulate the circulation of fresh water from the river and salt water from Puget Sound, and to simulate the distribution of biomass, dissolved oxygen (DO), and biochemical oxygen demand (BOD). An innovation in the model is its division into layers of the mixture of fresh and salt water that overlies the permanent salt-water wedge. Because estimates derived from the model have closely approximated the observed distributions of salinity in the estuary during several full tidal cycles, the circulation of salt and fresh waters in the estuary is considered to be simulated satisfactorily by the model. The next phase in the modeling will be an attempt to reproduce the observed distributions of chlorophyll-a, DO, and BOD that are produced by the water circulation and the growth and death cycle of organisms. Successful completion of the next phase will allow the model to be used to (1) study the causative factors in the depletion of DO from the salt wedge during low river flows in summer, and (2) predict the occurrence and magnitude of low DO.

[87]McKelvey, V. E., and Wang, F. F. H., 1969, World subsea mineral resources: U.S. Geol. Survey Misc. Geol. Inv. Map I-632. [Reprinted 1970, slightly revised]

Wind is the major cause of changes in water level in the large estuaries and sounds of coastal North Carolina because ocean tides are damped by the barrier islands that form the outer coast. The complex configuration of the interior shore line, however, makes the effect of a given wind at a given location hard to predict. G. G. Parker, Jr., and H. B. Wilder have developed a method for estimating wind-induced changes in water levels at several points in coastal North Carolina by modifying Ippen's[88] equation for setup caused by perpendicularly onshore winds blowing across water of constant depth:

$$S = \bar{h}\left[\sqrt{\frac{2kx}{g\bar{h}^2}U^2 + n} - n\right], \qquad (1)$$

where S = wind setup, or change in water level, in feet; $\bar{h}$ = average depth; k = constant empirically evaluated at 3.3×10^6; x = effective length, in miles, of water surface over which wind is acting—often called fetch; U = wind speed in miles per hour; and n = constant, which is unity in a rigorous solution of the deriving equation but can be empirically varied to obtain more precise estimates of S where calibration data are available for a specific location. To use the equation to estimate the change in water level caused by wind at some point along the shoreline of the sounds, it is necessary to determine the component of wind that will be effective in producing the greatest change. This will usually be the component acting along the longest continuous line of fetch to the point where the pileup of water is to be calculated. For a given wind, the component is calculated from the angle of departure of the actual wind direction from the effective line of fetch. By simple trigonometry the effective wind speed then becomes:

$$U_e = U_a \sin(90° - \alpha), \qquad (2)$$

where: U_e = effective wind speed,
U_a = actual wind speed; and
α = angle of departure of wind direction from the point of interest.

In practice, a curve is plotted from equation 1 showing S versus U_e. Where actual observations of S and U are available, they are used to adjust the constants in equation 1, and a final equation is developed which most precisely defines conditions at a specific location. A "wind compass" is developed on which the various angles of departure in equation 2 are plotted as adjustment coefficients. To determine setup for a given wind at a given location, it is necessary to use only the wind compass to determine the adjustment coefficient, multiply the actual wind speed by this coefficient, and consult the "S versus U_e" curve for that location.

Mathematical models have been used by L. A. Weiss (p. B211–B217, D165–D170) to compute the dispersion, temperature, and reaeration of waters in the Connecticut River estuary near the Connecticut Yankee Atomic Power Co. plant at Haddam Neck, Conn. The dispersion coefficient, which is highly dependent on the magnitude and direction of instantaneous water flow, varies from near zero to 3,000 sq ft per sec during a tidal cycle. The model is able to predict temperature at two cross sections within 1° Celsius. Reaeration coefficients, computed from a dissolved-oxygen survey made on August 27, 1968, ranged from 0.16 to 1.31 per day at 20° Celsius and were directly related to stream velocity. The most important controls on the distribution of dissolved oxygen were tidal advection and photosynthesis, although the effluent from the powerplant also seemed to affect the net production of oxygen.

Salinity and fresh-water inflow

A reconnaissance of the Winyah Bay estuary (including the Black, Pee Dee, Waccamaw, and Sampit Rivers) of South Carolina, by F. A. Johnson and S. J. Playton, has provided information on the relation of the chemical and physical characteristics of the water to tidal conditions and fresh-water discharge. The major rivers feeding Winyah Bay are moderately stratified, whereas Winyah Bay is usually highly stratified. Approximately 85 percent of the fresh-water inflow of the estuary moves to Winyah Bay through the Pee Dee River. During periods of low fresh-water inflow, salt water can be observed at high tide nearly 15 river miles upstream from the mouths of the inflowing rivers. During moderate to heavy fresh-water inflow, salt water does not generally extend more than 1 to 3 miles up the rivers at low tide and is sometimes confined entirely to Winyah Bay. Fresh-water quality is adequate for most domestic, industrial, and agricultural uses, and for the propagation of fish and other aquatic life.

A one-year study was commenced in 1970 by G. L. Faulkner and P. W. Bush to determine the movement of saline water, with respect to varying combinations of ocean tides and river discharge, in the Cross-Florida Barge Canal and the Lower Withlacoochee River between the Gulf of Mexico and Inglis Lock. Located about 7 miles inland, Inglis Lock is the westernmost lock on the partly completed canal. Data gathered in the river during the first half of the study suggest that at high tides sea water moved in along the river bottom less than half the 9-mile distance up the meandering river channel from the Gulf to the vicinity of Inglis Lock. At some low tides the river appeared to be free of sea water all the way to the Gulf. During the same periods, water of a salinity comparable to that of the nearshore Gulf water was present near bottom throughout much of the 7-mile length of the straight canal channel between the Gulf and Inglis Lock. Most of the time, fresh-water flow from above the lock ranged between 1,200 and 1,300 cfs in the river and 300 cfs or less in the canal.

[88]Ippen, A. T., 1966, Estuary and coastline hydrodynamics: New York, McGraw-Hill Book Co., p. 240.

Estuarine water quality

R. L. Cory[89] reported that continuous measurements of oxygen in the Patuxent River estuary, Maryland, over the period 1963 through 1969 revealed that a marked and progressive increase occurred in the summertime diurnal oxygen pulse. The increases are attributed to biostimulation from additions of sewage-plant effluents in the lower Patuxent River. Basic metabolism of the estuary over the period of record has been estimated by using Odum's open-water method of oxygen analysis. In 1964 maximum gross primary daily production of oxygen during the summer was about 6 g/m^2 and respiration was about 12 g/m^2. In 1969, maximum summer daily production of oxygen was about 25 g/m^2 and respiration was 23 g/m^2. Ratios of gross production of respiration (GP/R) averaged 0.84 in 1964 and 0.60 in 1969, indicating a trend toward instability in the estuarine ecosystem.

Similar measurements in the Rhode River estuary, Maryland, were carried out during 1970. Preliminary analysis indicates that the summertime metabolism is equal to or greater than that of the Patuxent during 1969. Sources of nutrient additions are from nearby farms and from large flocks of waterfowl that winter over in these protected (from hunters) waters.

MANAGEMENT OF NATURAL RESOURCES ON FEDERAL AND INDIAN LANDS

The Conservation Division is responsible for carrying out the U.S. Geological Survey's role in the management of the mineral and water resources on Federal and Indian land including the Outer Continental Shelf (OCS); that role includes, in particular, the conservation, evaluation, and development of the leasable mineral resources and waterpower potential of these areas. Primary functions are (1) mapping and evaluation of mineral lands; (2) delineation and preservation of potential public-land reservoir and waterpower sites; (3) promotion of orderly development, conservation, and proper utilization of mineral resources on Federal lands under lease; (4) supervision of mineral operations in a manner to assure protection of the environment and the realization of a fair value from the sale of leases and to obtain satisfactory royalties on mineral production; and (5) cooperation with other agencies in the management of Federal mineral and water resources.

[89]Cory, R. L., 1971, Primary production and diel oxygen measurements of the Patuxent Estuary, Maryland, 1963 through 1969, *in* FAO technical conference on Marine Pollution and its Effects on Living Resources and Fishing, Rome, Italy, Dec. 9–18, 1970: FAO Fisheries Rept. 99, sec. E-53, p. 151–152.

MAPPING AND EVALUATION OF MINERAL LANDS

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

Classified land

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

Geologic maps and studies developed to assist in mineral land classification are published in the regular Geological Survey publications series.

During fiscal year 1971, 223,000 acres of land were formally classified coal land, and 8,402 acres were classified phosphate land in the states of Colorado, Wyoming, Oregon, Utah, Alaska, and Montana, mainly as a result of the leasable mineral mapping program of the Geological Survey. Most of these lands were previously withdrawn to prevent alienation of the leasable minerals until an examination and classification could be made.

Geothermal resources standards

Standards for the classification of lands for retention of geothermal resources, in compliance with section 25 of the Geothermal Steam Act of 1970, were approved by the Director, U.S. Geological Survey, on March 9, 1971. The standards were prepared by Geological Survey geologists. Lands classifiable for retention for geothermal resources must contain (1) volcanism of late Tertiary or Quaternary age—exemplified especially by caldera structures, cones, and volcanic vents; (2) geysers, fumaroles, mud volcanoes, and thermal springs at least 40°F (about 22°C) higher than average ambient temperature; and (3) subsurface geothermal gradients generally in excess of two times normal, as reflected in shallow or deep water wells, oil wells, and other test holes.

Producing oil and gas structures

By the provisions of the Mineral Leasing Act of 1920, the Secretary of the Interior is authorized to grant to any applicant qualified under the act a lease to prospect for oil or gas on any part of the mineral estate of the United States that is not within any known geologic structure of a producing oil or gas field. Lands within such known structures are leased to the highest bidder. During fiscal year 1971, almost 1,260,000 acres of on-shore Federal land were determined to be in known geologic structures. The largest such structure defined during the year was the Recluse field, in Wyoming, which contains more than 16,000 acres.

WATERPOWER CLASSIFICATION—PRESERVATION OF RESERVOIR SITES

The objective of the waterpower classification program is to identify, evaluate, and segregate from disposal or adverse use all reservoir sites on public lands which have significant potential for future development. Such sites are an increasingly scarce and valuable natural resource. U.S. Geological Survey engineers study maps, photographs, and waterflow records to discover potential damsites and reservoir basins. Selected sites are mapped, and engineering and geologic studies are made to determine whether lands qualify for formal classification as valuable sites. Such resource studies provide land-administering agencies with information basic to management decisions on land disposal and multiple use. Previous classifications are reviewed as new data become available; if no longer considered suitable for reservoir development, land is released for return to the unencumbered public domain for other possible disposition. During fiscal year 1971 the review program was carried on in 16 river basins in the Western States and Alaska. The result, after needed additions and eliminations, was a net reduction of about 50,000 acres in lands classified as valuable water-resource development sites.

The Geological Survey conducts a limited specialized mapping program to aid in water-resources classification of areas not covered by maps of standard accuracy in the topographic quadrangle series. River basins are mapped at a scale of 1:24,000, and lake bottoms are contoured by precise sounding surveys. During fiscal year 1971, fieldwork was completed on damsite surveys in Washington and Oregon, and maps of several dam and reservoir sites in Oregon were published.

SUPERVISION OF MINERAL LEASING

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

Before recommending a lease or permit, Geological Survey engineers and geologists consider the possible effects upon the environment. Of major concern are the esthetic value of scenic and historic sites; the preservation of fish and wildlife and their breeding areas; and the prevention of land erosion, flooding, air pollution, and the release of toxic chemicals and dangerous materials. Consideration is also given to the amount and kind of mining-land reclamation which will be required.

Louisiana Outer Continental Shelf oil and gas lease sale

A sale of Federal Outer Continental Shelf leases was held in December, 1970. The sale was the largest Federal petroleum lease sale, financially, ever held. One hundred and twenty-seven tracts covering 593,000 acres were offered, and all received bids. High bids worth $851,388,599 were accepted

Table 1.—*Mineral production, value, and royalties for fiscal year 1971*[1]

Lands	Oil (barrels)	Gas (thousand cubic feet)	Gas liquids (gallons)	Other[2] (tons)	Value (dollars)	Royalty (dollars)
Public	191,411,000	943,980,000	579,189,000	29,584,000	$ 926,854,000	$ 98,844,000
Acquired	10,613,000	36,280,000	2,169,000	487,600	101,331,000	7,549,000
Indian	31,912,000	125,584,000	50,348,000	11,351,000	159,564,000	19,707,000
Military	675,000	23,332,000	25,533,000	...	7,396,000	1,183,000
Outer Continental Shelf	398,113,000	2,510,913,000	1,308,424,000	960,750	1,910,515,000	316,559,000
Naval Petroleum Reserve Number 2.	5,533,000	5,393,000	11,344,000	...	12,037,000	1,627,000
Total	638,257,000	3,645,482,000	1,977,007,000	42,383,350	$3,117,697,000	$445,469,000

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

for 116 of the tracts. The highest accepted bid was $12,874.79 per acre, a record for a wildcat lease on the U.S. Gulf of Mexico Outer Continental Shelf. Since the sale, more than 50 wells have been drilled on about 30 of these tracts, leading to the discovery of 13 gas fields, three oil fields, six combination oil and gas fields, and the extension of one oil field. U.S. Geological Survey engineers, geologists, and geophysicists prepared evaluation studies and reports leading to minimum acceptable bids for each lease block offered.

COOPERATION WITH OTHER FEDERAL AGENCIES

The U.S. Geological Survey acts as a consultant to other Federal agencies in land-disposal cases. In response to their requests, determinations are made as to the mineral character of specific tracts of Federal lands under their supervision which are proposed for sale, exchange, or other disposal. More than 4,000 such reports were made during fiscal year 1971, and nearly 11,000 reports were made on Federal oil and gas lands proposed for leasing.

Nuclear devices on Federal leaseholds

In September 1969, a 40-kiloton underground nuclear device was detonated by the U.S. Atomic Energy Commission in the Hayward well of the Rulison oil and gas development unit, near Rifle, Colo. The purpose of the explosion was to increase gas production by fracturing the gas-bearing sedimentary rocks. The explosion fractured the sedimentary rocks, and increased the flow of gas, but the gas was radioactive and of low methane content. Methane is almost always the major constituent of natural gas. Since the explosion, the amount of radioactivity in the gas has dropped almost to a level which many experts consider to be permissible in natural gas for public use, and the methane content of the gas is increasing. Interested industrial and governmental organizations are continuing to work toward improving devices and procedures to make nuclear fracturing economic, and to find a safe use for low-level radioactive gas.

EXPERIMENTAL GEOPHYSICS

CRUST AND MANTLE STUDIES

Structure in eastern Montana

Interpretation has continued on both explosion and earthquake seismic measurements in the region of the Large Aperture Seismic Array (LASA). On the basis of a study of traveltime residuals from teleseisms at different azimuths around LASA, H. M. Iyer found that the region was underlain by a northeast-trending synclinal structure on the M discontinuity. Iyer also concluded that the unexplained part of the residuals might be caused by fluctuations in the thickness of an upper-mantle low-velocity layer which is probably associated with the tectonic transition from the active mountains of the west to the Great Plains of the east.[90] Studies of explosions by D. H. Warren, using reflections from the top of the mantle, show a crust-mantle boundary structure in reasonable agreement with that found by Iyer from earthquake data.

Structure of the Mono Basin, Calif.

Seismic data from nine shotpoints in Mono Lake are being interpreted by L. C. Pakiser in an attempt to resolve discrepancies in basin-structure interpretations by different investigators. The interpretation indicates that Mono Basin is bounded by faults and is filled with about 2 km of sedimentary and volcanic deposits of Cenozoic age. Aeromagnetic data reveal that volcanic activity near the center of the basin has been great. These results are being used to guide drilling to test the geothermal power potential of Mono Basin.

Crustal structure of the Western United States

Claus Prodehl (visiting scientist from Geophysikalisches Institut der Universität, Karlsruhe) has reinterpreted 64 explosion seismology profiles from the western conterminous States (r0639) by methods developed by Giese (Free University of Berlin). He has combined the results into a broad regional study. The major features, such as crustal thickness and mean crustal velocity, are in general agreement with the earlier interpretations, although occasional differences do exist.

The Giese method is particularly useful in detecting low-velocity zones within the crust. Prodehl compared his results with those from central Europe.[91] He concluded that low-velocity zones are occasionally found in the Western United States but are not as widespread as they are in the Alps and in Germany. The question of low-velocity zones remains an active subject for discussion in explosion seismology.

Theoretical amplitudes of seismic refracted waves

D. P. Hill studied the character of the amplitudes of seismic refracted waves recorded in explosion surveys. Amplitudes are very sensitive to boundary curvature and to small velocity gradients. Wave-theoretical spectra show that the refracted wave may decay either by the same amount or by more than the classical head wave, depending on whether the refractor gradient is the same or less than, respectively, the critical value. For larger velocity gradients the spectrum is scalloped and the amplitudes decay less rapidly than the classical head wave. At sufficiently long distances, separate diving waves can be identified.

GEOTHERMAL STUDIES

Heat-flow map of the Western United States

Heat-flow data for the Western United States (fig. 5) have been more than doubled with about 150 new values recently reported by J. H. Sass, A. H. Lachenbruch, R. J. Munroe, G. W. Greene, and T. H. Moses, Jr.[92] The results were obtained after analysis of thermal data obtained by the U.S. Geological Survey at about 1,000 drilling sites over the past decade. The

[90] Iyer, H. M., and Healy, J. H., 1971, Teleseismic residuals at the LASA-USGS extended array and their interpretation in terms of crust and upper mantle structure: Jour. Geophys. Research. [In press]

[91] Prodehl, Claus, 1970, Crustal structure of the western United States from seismic refraction measurements in comparison with central European results: Zeitschrift fur Geophysik, v. 36, p. 477–500.

[92] Sass, J. H., Lachenbruch, A. H., Munroe, R. J., Greene, G. W., and Moses, T. H., Jr., 1971, Heat flow in the Western United States: Jour. Geophys. Research, v. 76, no. 26. [In press]

new data confirm that heat flow is variable, but generally high, west of the Great Plains. Within the overall pattern of high heat flow, the results show several areas (each occupying 10^3–10^4 km^2) of low-to-normal heat flow, and one area (in north-central Nevada) where average heat flow is about 50 percent higher than the average for the Great Basin. Some of the low heat-flow areas such as the Sierra Nevada are zones of low crust and upper mantle temperatures, whereas one in the Great Basin may be a region of very deep hydrologic recharge to depths on the order of 3 km. The high heat-flow area in Nevada probably has higher-than-average temperatures at relatively shallow depths and may be a suitable target for systematic studies related to geothermal power potential.

The new data indicate that the transition from low heat flow in the Sierra Nevada to high heat flow in the Basin and Range province occurs over a lateral distance on the order of one crustal thickness or less. Data for California are now sufficiently dense to indicate gross relations between heat flow and major tectonic features, such as the Sierra Nevada, Great Valley, and Coast Ranges.

Vertical distribution of heat-producing elements in the continental crust

It has recently been discovered that heat flow is a linear function of heat production for plutonic rocks in several large

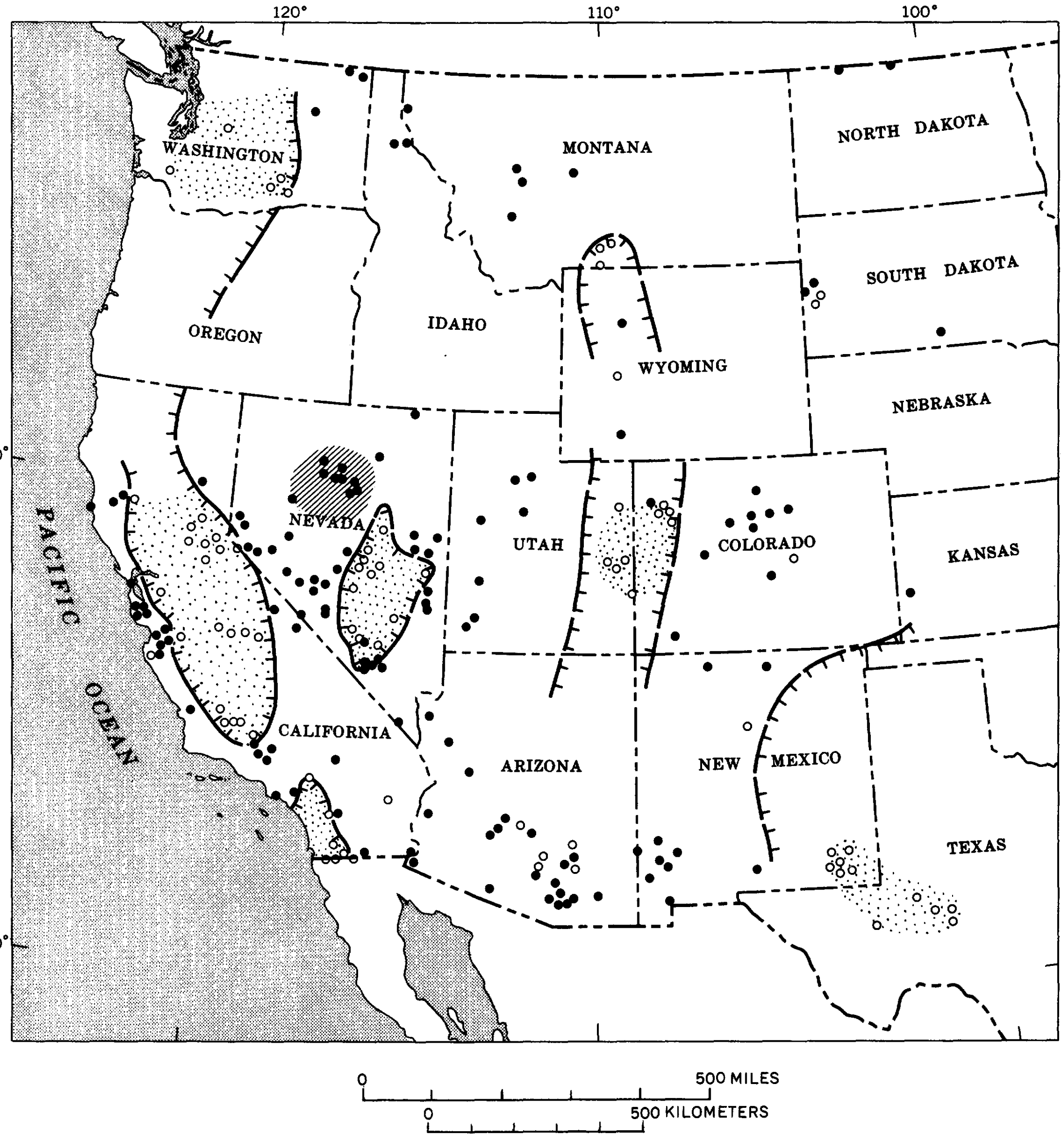

Figure 5.—Generalized representation of heat-flow data from the Western United States. Open circles represent measured values less than 1.5 heat-flow units; solid circles represent higher measured values. The stippled areas are characterized by heat flow of 1.5 and less; the heavy lines are 1.5-heat-flow-unit contours. The cross-hatched area is characterized by heat flow of 2.5 and greater. (From Sass, Lachenbruch, Munroe, Green, and Moses.[92])

geographic provinces. From these results, it can be shown that the heat production in the underlying crust probably has a simple generalized depth distribution, and that if appreciable differential erosion has occurred, this distribution must be an exponential function with parameters that can be determined from surface observations[93] (A. H. Lachenbruch, r0066). If the rate of change of heat production with depth could be determined in deep boreholes, the form of this crustal source distribution could be estimated by independent means. A theoretical analysis of the sampling problem by A. H. Lachenbruch[94] shows that the detection of such trends would require several boreholes to depths of a few kilometers. Analysis of samples from eight boreholes in granite by A. H. Lachenbruch and C. M. Bunker[95] confirms the sampling theory and suggests a decrease in heat production with depth consistent with the theoretically derived exponential model.

Relation between heat flow and topographic relief at sea-floor spreading centers

Evidence is accumulating that the Alpha-Mendeleyev Cordillera in the Arctic Ocean is an extinct sea-floor spreading center.[96,97,98] With more than 300 heat-flow measurements, A. H. Lachenbruch and B. V. Marshall determined that the heat flow on the Cordillera is lower than average, and it can be inferred that temperatures in the lithosphere beneath it cannot be significantly higher than beneath the surrounding basins.

Several recent views[99,100] attribute the relief on actively spreading ocean ridges to thermal expansion of the anomalously hot underlying lithosphere. They are inconsistent with the observation that the relief (2 km) on the cooled-off Alpha-Mendeleyev Cordillera is comparable to that on active modern spreading centers. These observations suggest important constraints for theories of the mechanism of sea-floor spreading.

Explanation for anomalously deep permafrost at Prudhoe Bay, Alaska

Temperatures measured and analyzed by A. H. Lachenbruch and T. H. Moses, Jr., near Prudhoe Bay, Alaska, confirm that the permafrost there is the deepest yet reported from North America (600 m). The heat flow is normal, and the anomalously deep permafrost results from the high conductivity of ice-rich siliceous sediment which produces a small geothermal gradient. In thawed sediment beneath the permafrost the gradients are large, and temperatures at 2,750 m exceed 100°C. The climatic warming of a few degrees in the last century observed elsewhere on the Arctic Coast is also evident at Prudhoe Bay.

Thermal events and deep circulation beneath hot springs

Water feeding the hot springs in southwestern Montana apparently circulates in stable conduits to a depth between 2 and 5 km, but no clear relationship with topography, geological formation, or structure has been found. In studying this problem, E. C. Robertson used the following types of observations to determine the depths: The temperature of the spring water issuing at the surface, the maximum temperature gradients in nearby drill holes, the mean annual surface temperature, and the heat-transfer coefficient between water and rock on a deep level in a Butte mine. Judging by the uniformity in temperature (within 1°C) and in volume of flow, for 4 yr of measurement of the hot springs, there is no temperature effect due to mingling with surface or ground water either in the initial gathering area or along the path back to the surface. Therefore, small secular changes in hot-spring temperatures might reflect changes in the heated rock below; they could indicate deep-seated intrusive events, or could even be precursors of tectonic events like vertical or lateral creep or earthquakes.

ROCK MAGNETISM

Geomagnetic secular variation in the Pacific basin

At the present time secular variation of the earth's magnetic field is much subdued over a large part of the Pacific basin in comparison with the rest of the world. This difference is probably due to large-scale lateral differences in the kinds of fluid motions in the earth's outer core. By analyzing paleomagnetic data from over a thousand lava flows less than 0.7 m.y. old from eight widely separated areas in the world and from many more older lavas from the Hawaiian Islands, R. R. Doell (r0890) and A. V. Cox have demonstrated that the anomalously low secular variation in the Pacific has been a persistent feature for at least the past 5.5 m.y. Elsewhere, the magnitude

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[93]Lachenbruch, A. H., 1968, Preliminary geothermal model of the Sierra Nevada: Jour. Geophys. Research, v. 73, p. 6977–6989.

[94]Lachenbruch, A. H., 1971, Vertical gradients of heat production in the continental crust, 1. Theoretical detectability from near-surface measurements: Jour. Geophys. Research. [In press]

[95]Lachenbruch, A. H., and Bunker, C. M., 1971, Vertical gradients of heat production in the continental crust, 2. Some estimates from borehole data: Jour. Geophys. Research. [In press]

[96]Hall, J. K., 1971, Geophysical evidence for ancient sea-floor spreading from Alpha Cordillera and Mendeleyev ridge [abs.]: Second Internat. Symposium on Arctic Geology, Am. Assoc. Petroleum Geologists, San Francisco, 1971, Program Abs., p. 23–24.

[97]Lachenbruch, A. H., and Marshall, B. V., 1966, Heat flow through the Arctic Ocean floor—The Canada Basin-Alpha Rise Boundary: Jour. Geophys. Research, v. 71, p. 1223–1248.

[98]Wold, R. J., and Ostenso, N. A., 1971, Aeromagnetic evidence for origin of Arctic Ocean basin [abs.]: Second Internat. Symposium on Arctic Geology, Am. Assoc. Petroleum Geologists, San Francisco, 1971, Program Abs., p. 56.

[99]McKenzie, D. P., and Sclater, J. G., 1969, Heat flow in the Eastern Pacific and sea floor spreading: Bull. Volcanol., v. 33, no. 1, p. 101–117.

[100]Oxburgh, E. R., 1971, Plate tectonics, *in* Gass, I. G., Smith, P. J., and Wilson, R. C. L., eds., Understanding the Earth, A reader in earth sciences: Sussex, England, Artemis Press, p. 263–285.

of secular variation for the past 0.7 m.y. has varied as a function of latitude much as does the present field. This indicates that in the past the magnitudes of the dipole and nondipole parts of the geomagnetic field had on the average the same relative proportion as they do now (A. V. Cox, r0511). Doell and Cox have shown that their results are consistent with a pronounced attenuation of the geomagnetic variation spectrum in the period range of 200 to 2,000 yr in the area of the central Pacific. From this they conclude that a lateral inhomogeneity exists in the lower mantle that is coupled to the core in such a way as to inhibit the generation, in the outer core beneath that area, of nondipole magnetic fluctuations with periods in this range.

Geomagnetic reversal time scale

Further refinements and clarification of the reversal time scale have resulted from paleomagnetic studies of East African rocks by C. S. Grommé. The Olduvai normal polarity event is represented in its type area by rocks ranging in age from 1.6 to 1.9 m.y. and can be no older than 2.0 m.y. (C. S. Grommé, r1712, and R. L. Hay). Many dated lavas that were originally assigned to the Olduvai event are now seen to represent one or two earlier and much shorter normal polarity events which are now designated the Réunion events. The transition from the Gauss normal epoch to the Matuyama reversed epoch is represented in lavas forming the walls of Ngorongoro caldera, and has been dated by the potassium-argon method at 2.45 m.y. These revisions (C. S. Grommé and others, r1562) bring the directly determined geomagnetic time scale into conformity with the one implied by assumptions of uniform sedimentation rates on the ocean floor and uniform rates of sea-floor spreading.

Paleomagnetic correlations of welded tuff sheets

In comparison with other eruptive rocks, ignimbrites (ash-flow tuffs) often have remarkably broad lateral extents and thus can be very useful structural and stratigraphic markers. A. V. Cox has investigated the paleomagnetism of a series of late Cenozoic ignimbrites in New Zealand and has shown that they may be classified into two groups on the basis of their directions of natural remanent magnetism. There is a high statistical probability that each of the two groups was erupted in a short time relative to geomagnetic secular variation, that is, within a few centuries. C. S. Grommé, E. H. McKee, and M. C. Blake, Jr., have conducted a detailed study of several of the middle Tertiary ignimbrites that are widespread in the eastern Great Basin. Using the probability argument developed by Cox, it can be shown that each cooling unit in these volcanic rocks is characterized by a unique direction of magnetization.[101] Hence it has proved possible to correlate individual cooling units unambiguously over distances as great as 200 km, confirming most of the correlations that were originally made on lithologic and stratigraphic grounds. The volumes of the products of these single eruptions are as great as 1,300 km^3 and cover areas up to 8,200 km^2. The time between eruptions was no shorter than several thousand years and, in general, was of the order of several tens of thousands of years or more.

COMPUTER MODELING OF GEOLOGIC PROCESSES

J. H. Dieterich (r1194) studied the dynamics of fault slip by means of finite-element calculations on a digital computer. The calculation assumes that motion on the fault is governed by the classical laws of friction, and variations along the fault in both initial stress and friction coefficients are admitted. The model not only yields the details of stress relaxation and slip for a single seismic event but also generates a sequence of events when the fault blocks are assumed to be driven by a uniform rate of tectonic loading. The program has been modified to include the effects of fluid injection and simulates realistic earthquake sequences which may be compared to the results of the Rangely earthquake modification experiment.

R. G. Henderson reports that the quantitative interpretation of magnetic and gravity anomaly maps is facilitated by transforming the problem from the space domain to the wave-number domain. In the wave-number domain the field is studied in terms of the sinusoidal waves of which it may be thought to be composed. Rather simple formulas emerge relating the field to parameters of the disturbing body such as depth, dip, and size.

A well-known relation between the magnetic and gravity anomaly from the same source was used to develop a system for studying bulk remanent magnetization and density. The direction of total magnetization may be determined uniquely, but the direction of remanent magnetization must be derived under more restricted conditions. The method was successfully used by L. E. Cordell, (USGS) and P. T. Taylor (U.S. Naval Oceanographic Office) to estimate the remanent magnetism and pole position of a North Atlantic seamount.[102]

GEOCHEMISTRY, MINERALOGY, AND PETROLOGY

EXPERIMENTAL GEOCHEMISTRY

Calculation of thermochemical data from hydrothermal experiments

E-an Zen and J. R. Fisher have computed tables of the standard Gibbs free energy of formation of H_2O using the

[101] Cox, A. V., 1969, A paleomagnetic study of secular variation in New Zealand: Earth and Planetary Sci. Letters, v. 6, p. 257–267.

[102] Cordell, Lindrith, and Taylor, P. T., 1971, Investigation of magnetization and density of a North Atlantic seamount using Poisson's theorem: Geophysics, v. 36, no. 5. [In press]

latest P-V-T data of Burnham and others.[103] The data in this form greatly aid interpretation of thermodynamic calculations on hydration-dehydration reactions applied both to the laboratory and to the earth. Thermodynamic calculations were checked by using experimental stability data on brucite to derive its standard Gibbs free energy of formation (298°K, 1 bar) from the elements. This example was chosen because there are excellent experimental data both on the stability of brucite and on calorimetric measurements of its Gibbs free energy of formation. The results are in excellent agreement relative to the respective uncertainties of measurement and calculation (J. R. Fisher, r1900, and E-an Zen).

E-an Zen[104] has applied the above methods to calculations of the standard Gibbs free energy of formation, the standard enthalpy of formation and the standard third law entropy (all at 298°K, 1 bar) for a suite of minerals each of which takes part in one or more hydrothermal reactions for which there are published P-T brackets. The results give thermodynamic data for diaspore, tremolite, zoisite, prehnite, wairakite, laumontite, muscovite, paragonite, clinochlore, anthophyllite, and pyrophyllite. It was found that the calculated values for muscovite show major disagreements with direct calorimetric measurements, suggesting that major revisions may be needed in calculated mineral stabilities involving or derived from thermochemical data for muscovite. The heat of formation for anthophyllite (E-an Zen, r1322) is also drastically different from published values derived in other ways from stability data, again indicating need for revision of any conclusions based on such heats of reaction. The results for chlorite suggest that this mineral has a greater range of stability than was previously supposed, and this may be particularly important to calculations of mineral assemblages in sedimentary rocks. An interesting aspect of the results for zeolite minerals was found in anomalously high entropy values for H_2O in the structure, even larger than those of liquid water. This indicates weakly constrained motions of H_2O molecules within their structural sites relative to the states of H_2O in other hydrous minerals and even relative to liquid water.

Fluid inclusions

E. W. Roedder has refined methods for crushing small grains containing fluid inclusions while they are viewed on the microscope stage so that now he can detect as little as 10^{-14} g of noncondensable gases (less than a billion molecules). The technique proved useful for detecting maximum rates of leakage of some inclusions and rates of diffusion of air through obsidian. It also proved useful in estimating pressures at the time of mineral formation in some ore deposits.[105]

Stability of carbonate minerals in aqueous solutions at low temperatures

C. L. Christ and P. B. Hostetler[106] have shown that magnesite is the stable mineral phase in the system $MgCO_3-H_2O$ at low temperatures and pressures appropriate to sedimentary environments. This conclusion based on thermodynamic evidence agrees with the common sedimentary occurrence of magnesite, but this occurrence was always considered something of an enigma because, although magnesite clearly forms readily in sediments, it could not be produced in the laboratory under the same conditions of temperature and pressure. Instead, when magnesium and carbonate ions are mixed in aqueous solution the product is either one of two hydrous phases, hydromagnesite or nesquehonite. Christ and Hostetler therefore deduced that this happens because of strong bonding between magnesium cations and water molecules. Experiments were then designed to strip the water from these ions by adding either lithium chloride or ethylene glycol to the solutions to lower the activity of H_2O. Under these conditions, magnesite formed almost immediately at 90°C and within one week at 25°C. Similar experiments containing both magnesium and calcium ions produced protodolomite. The results show that the activity of water has a major influence on the kinetics of mineral formation. This effect may also be of great importance in controlling growth mechanisms for the highly polymerized structures found in borate and silicate minerals.

Absorption of gold in growing plants

H. T. Shacklette, H. W. Lakin, A. E. Hubert, and G. C. Curtin[107] used radioactive gold as a tracer in laboratory experiments on movements of gold into and through cultivated plants. The distribution was detected after each experiment by means of autoradiographs. The action of roots on gold chloride was found to reduce the gold to colloidal form that did not pass through root tissues, although it did enter cut stems. Gold as thiosulfate behaved similarly. By contrast, radioactive gold in solutions of gold cyanide, bromide, iodide and thiocyanate was absorbed through root membranes and was transported to stems and leaves. Atomic absorption analysis showed that gold as gold cyanide constituted as much as 320 ppm of the dry weight of plants whose roots were

[103] Burnham, C. W., Holloway, J. R., and Davis, N. F., 1969, Thermodynamic properties of water to 1,000°C and 10,000 bars: Geol. Soc. America Spec. Paper 132, 96 p.

[104] Zen, E-an, 1969, Free energy of formation of pyrophyllite from hydrothermal data—Values, discrepancies and implications: Am. Mineralogist, v. 54, p. 1592–1606.

[105] Roedder, E. W., 1970, Application of an improved crushing microscope stage to studies of gases in fluid inclusions: Schweizer. Mineralog. U. Petrog. Mitt., v. 50, p. 41–58.

[106] Christ, C. L., and Hostetler, P. B., 1970, Studies in the system $MgO-SiO_2-CO_2-H_2O(II)$—The activity-product constant of magnesite: Am. Jour. Sci., v. 268, p. 439–453.

[107] Shacklette, H. T., Lakin, H. W., Hubert, A. E., and Curtin, G. C., 1970, Absorption of gold by plants. U.S. Geol. Survey Bull. 1314-B, p. B1–B23.

immersed in solutions of this compound. Furthermore, radioactive gold solubilized by an extract from flax plants that contained hydrogen cyanide derived by enzymatic action on the natural glycoside was absorbed in large amounts by the experimental plants. These experiments show that if gold is present in the soil where cyanogenic plants are rooted, a mechanism exists for introducing gold into the biogeochemical cycle.

MINERALOGIC STUDIES IN CRYSTAL CHEMISTRY

CRYSTAL CHEMISTRY OF ROCK-FORMING SILICATES

Site occupancies in synthetic $(Ca,Fe)SiO_3$

Assignments and area ratios for the *M*1 and *M*2 sites have been determined by Eric Dowty and D. H. Lindsley[108] for both room- and liquid-nitrogen temperature Mössbauer spectra of a series of synthetic hedenbergite-ferrosilite pyroxenes quenched from 950°C and 20 kb. Variations in quadrupole splitting for the *M*2 site illustrate the crystal chemical basis for some of the phase relations of pyroxenes. Quadrupole splitting for *M*2 decreases to a minimum at about $Fs_{83}Wo_{17}$, indicating maximum distortion (and highest energy) of the immediate environment of the site at this composition. In fact, the curve of isomer shift versus composition is suggestive of an inverted solvus. Area ratios for liquid-nitrogen temperature spectra are fairly precise and show a slight excess of iron in the *M*1 site for compositions other than Fs_{100}, indicating that a small amount of calcium (a maximum of about 0.04 atoms) may be found in the *M*1 site. The area ratios from the room-temperature spectra are anomalous although the hyperfine parameters seem to be consistent with those of the liquid-nitrogen spectra. Areas of the *M*2 doublet for relatively calcic compositions, such as $Fs_{70}Wo_{30}$, remain almost equal to the areas of the *M*1 doublet although they should be much smaller. The cause of this anomaly is not fully understood, but it is apparent that site distributions of calcic pyroxenes determined from room-temperature spectra may be seriously in error.

The anthophyllite-gedrite and actinolite-hornblende solid-solution series

Evaluation of available chemical analyses by Peter Robinson (University of Massachusetts), Malcolm Ross (USGS), H. W. Jaffe (University of Massachusetts), and Cornelis Klein (Harvard University)[109] indicates the anthophyllite-gedrite series is a solid solution between two end members

$$\mathrm{o}R^{2+}_{2}R^{2+}_{5}Si_8O_{22}(OH)_2 \text{ and}$$

$$Na_{0.5}R^{2+}_{2}(R^{2+}_{3.5}R^{3+}_{1.5})Si_6Al_2O_{22}(OH)_2,$$

where R^{2+}=Mg, Fe^{2+}, Mn^{2+}, Ca; R^{3+} = Al, Fe^{3+}, $(Fe^{2+}_{1/2}+Ti^{4+}_{1/2})$; and o=vacant *A* site. A similar evaluation of calcic amphiboles suggests that a high proportion fall in an actinolite-hornblende series between two analogous end members

$$\mathrm{o}Ca_2R^{2+}_{5}Si_8O_{22}(OH)_2 \text{ and}$$

$$Na_{0.6}Ca_2(R^{2+}_{3.6}R^{3+}_{1.4})Si_6Al_2O_{22}(OH)_2.$$

Calcic amphiboles between actinolite and ideal edenite, tschermakite, or pargasite are rare. The apparent coupling of the two coupled substitutions, one, *A*-site Na and Al(IV) for the *A*-site vacancy and Si(IV); and two, R^{3+}(VI) and Al(IV) for R^{2+}(VI) and Si(IV), and the half-occupied *A* site implied by the ideal gedrite and hornblende formulas are not readily explained by determined gedrite and hornblende structures.

There is apparently complete solid solution in the anthophyllite-gedrite series at high temperature as demonstrated in specimens from the sillimanite zone of southwestern New Hampshire and Massachusetts. On cooling, members with intermediate Al and Na content exsolved to an anthophyllite-gedrite intergrowth as shown by X-ray single crystal photographs. Some of the intergrowths are coarse enough so that (010) lamellae of anthophyllite (0.2μ thick) and gedrite (0.8μ thick) are visible under the petrographic microscope. Other intergrowths are optically homogeneous but show a strong blue, green, or yellow Schiller effect believed to be due to submicroscopic exsolution. Exsolved anthophyllite and gedrite lamellae in the New Hampshire and Massachusetts intergrowths are estimated to contain approximately 0.2 and 1.6 tetrahedral Al, respectively. The Fe-Mg ratio is believed to have little influence on the width of the solvus in the composition range of the specimens studied. Under conditions of primary crystallization below the crest of the solvus, as reported by Stout[110] from Southern Norway, anthophyllite and gedrite, with tetrahedral Al contents in the ranges 0.29 to 0.47 and 1.13 to 1.50, respectively, formed together as two physically separable phases which subsequently underwent no fine-scale exsolution.

The composition limits of the anthophyllite-gedrite field under given metamorphic conditions are set both by the crystal chemistry and free energy of the orthoamphiboles, and the relative free energies of competing phases. The appearance of a primary anthophyllite-gedrite solvus further complicates an already complex set of metamorphic facies types.

CRYSTAL CHEMISTRY OF TITANIAN GARNETS

The question of whether titanium replaces silicon in garnets

[108] Dowty, Eric, and Lindsley, D. H., 1971, Mössbauer spectroscopy of synthetic Ca-Fe pyroxenes: Carnegie Inst. Washington Year Book, v. 69, p. 190–193.

[109] Robinson, Peter, Ross, Malcolm, Jaffe, H. W., and Klein, C., 1971, Composition of the anthophyllite-gedrite series, comparison of gedrite and hornblende, and the anthophyllite-gedrite solvus: Am. Mineralogist, v. 56, p. 1005–1041.

[110] Stout, J. H., 1971, Four coexisting amphiboles from Telemark, Norway: Am. Mineralogist, v. 56, p. 212–224.

has been debatable despite much recent work in the literature. It is impossible to determine the site distribution of cations in titanian garnet by any single method because there are too many chemical variables; site distributions of Fe, Al and Ti are all unknown. Eric Dowty (r0490) and D. E. Appleman have combined data from X-ray structure refinement and Mössbauer spectroscopy, enabling the site distribution of most of the titanium to be pinned down. There seems to be very little, if any, tetrahedral titanium. A result of Mössbauer study has been the apparent confirmation of a small amount of ferrous iron replacing silicon. Replacement of silicon by a large ion like Fe^{2+} is astonishing.

An analysis of a high zirconium, high titanium garnet from Magnet Cove, Ark., by J. J. Fahey has helped to delineate bulk chemical variation in Ti-Zr garnets. Although data are still very scarce for Zr garnets, there seem to be two series: one between andradite and end-member schorlomite (about $Ca_3TiFe^{3+}(Fe^{3+},Al)Si_2O_{12}$), and one between schorlomite and kimzeyite ($Ca_3Zr_2(Al,Fe^{3+})Si_2O_{12}$).

POTASSIUM-RICH MICROCLINES FROM THE WET MOUNTAINS, COLO.

Eight microcline samples, each representing a more or less distinct paragenetic type, collected from zones of potassic fenitization in the Wet Mountains, Colo., were studied by George Phair using recently developed X-ray diffraction procedures developed by P. M. Orville, by T. L. Wright, and by T. L. Wright and D. B. Stewart. Five of the samples had been chemically analyzed. Orville's heating method using ($\bar{2}01$), together with Orville's curves as refined especially for K-rich microcline, determined Or contents closest to those of the chemically analyzed samples. Following in order of decreasing accuracy were Or contents as determined by (1) cell parameter, *a*, (2) cell parameters *V*, and (3) ($\bar{2}01$) unheated. In no determination was the difference found to be greater than 4.5 percent Or.

The six samples for which full data are available are all excellent maximum microcline. All samples appeared normal when using Wright's criterion, $2\theta(\bar{2}01)_{\text{theor.}} - 2\theta(\bar{2}01)_{\text{meas.}} < 0.1^\circ 2\theta$; one of the six appears slightly anomalous when using Wright and Stewart's criterion for normality: $a_{\text{theor.}} - a_{\text{meas.}} < 0.02$ A. The measured "triclinicities" (Δ) of the six samples using Laves' relationship, $\Delta = 12.5[2\theta(1\bar{3}1) - 2\theta(131)]$ closely fit a smooth curve when plotted against the difference between axial angles α and γ. The "triclinicity" decreases from 0.97 in the naturally heat treated but chemically unaltered granite to 0.93 in residual microcline from the fenite zone, to 0.87 in the newly formed replacement microcline in the fenite zone, and finally to 0.85 in the tabular microcline found in open spaces in the central "vein." The differences in "triclinicity" indicate progressively increasing structural disorder. A low, but distinct, temperature gradient increasing from the wallrocks through the emplacement zone into the central vein is indicated. The large size and semieuhedral morphology of the most disordered crystals is incompatible with rapid deposition as the cause of disorder. The nearly complete lack of Ab+An component in the microcline, the very low thermal state, and the lack of gridiron twinning shown by the microcline, all indicate that unusually low temperatures prevailed during mineral formation throughout the potassic fenite zone.

NEW MINERAL DATA FOR HYDRATED PHOSPHATES AND SULFATES

Chemical and X-ray crystallographic studies by M. E. Mrose have demonstrated that the mineral dittmarite, previously assigned the formula $(NH_4)Mg_5H_4(PO_4)_5 \cdot 8H_2O$, is actually $(NH_4)MgPO_4 \cdot H_2O$, orthorhombic, $Pmn2_1$, *a* 5.606, *b* 8.758, *c* 4.788 A, cell volume 235.1 A^3, cell contents $2[(NH_4)MgPO_4 \cdot H_2O]$, density (calc.) 2.19 g/cm^3. Supposed "hannayite" is found to be a mixture of two phases: newberyite, $MgHPO_4 \cdot 3H_2O$, and dittmarite. Crystals of struvite, $(NH_4)MgPO_4 \cdot 6H_2O$, a mineral associated with newberyite and dittmarite, are found to alter when held in mother liquor for several weeks at about 55°C, producing first dittmarite and then newberyite. The reaction is reversible, and newberyite crystals kept over NH_4OH in a closed system for several months alter to struvite. These results explain the mineral associations and account for the previous confusion about this system.

The first known occurrence in the United States of the rare mineral, wagnerite, Mg_2PO_4F, is at Santa Fe Mountain, near Idaho Springs, Colo. X-ray diffraction studies of the crystals by M. E. Mrose show that the mineral is monoclinic, $P2_1/a$, *a* 11.929±0.005, *b* 12.698±0.008, *c* 9.633±0.004 A, β 108°12′±3′, cell volume 1,386 A^3, cell contents $16[Mg_2PO_4F]$, density (obs.) 3.13 g/cm^3, (calc.) 3.12 g/cm^3. The mineral has a strong subcell with $I2/a$ symmetry and the same *a*, *c*, and β values as the true cell but with *b* one-half of the true cell. Ferroan wagnerite, $(Mg,Fe,Mn)_2PO_4(F,OH)$ and magniotriplite, $(Mg,Fe,Mn)_2PO_4F$, have the same $I2/a$ space-group as does triplite, $(Mn,Fe,Mg,Ca)_2PO_4(F,OH)$. The cell dimensions for ferroan wagnerite are *a* 11.971, *b* 6.381, *c* 9.714 A, β 108°15′, and for magniotriplite, *a* 12.015, *b* 6.415, *c* 9.787 A, β 108°10′. The close agreement of the cell constants and the triplitelike space-group symmetry indicate that the name, ferroan wagnerite, should be relegated to synonomy, and magniotriplite should be used instead.

Type trudellite from the Cerro Pintados, 80 km southeast of Iquique, Tarapaca province, Chile, originally assigned the formula $Al_{10}Cl_{12}(OH)_{12}(SO_4)_3 \cdot 30H_2O$ (?), has been shown by X-ray and chemical studies (M. E. Mrose) to be a mixture of two phases, natroalunite, $NaAl_3(SO_4)_2(OH)_6$, and chloraluminite, $AlCl_3 \cdot 6H_2O$. The latter mineral has previously been found only in acid fumaroles on Vesuvius, Italy, during the eruptions of 1872 and 1906. The present work thus discredits the species trudellite and establishes a new occurrence for chloraluminite.

CRYSTAL CHEMISTRY OF DAWSONITE, OF A NEW VANADIUM SILICATE, AND OF GOWERITE

The crystal structure of dawsonite, $NaAl(CO_3)(OH)_2$, was redetermined by D. E. Appleman and M. E. Mrose using the symbolic addition procedure on data obtained from a crystal from Green River cores. Least-squares refinement of the very accurate data confirms the preliminary structure found by Frueh and Golightly,[111] and in addition, reveals the hydrogen-bonding scheme. The hydrogen atom was resolved and its position refined.

An orthorhombic dimorph of the new mineral cavansite, $Ca(VO)(Si_4O_{10}) \cdot 4H_2O$, has been discovered by H. T. Evans, Jr. (r0492), in specimens collected by Professor Lloyd Staples (University of Oregon) at Owyhee, Oreg. The new phase forms blue-green prismatic crystals hardly distinguishable from cavansite except that they are invariably twinned, often in fivelings with striking star-shaped cross sections. The structure of this phase has been solved and found to be a layer silicate structure like cavansite, whose structure determination was previously reported in Prof. Paper 700-A (U.S. Geol. Survey, r0632, p. A118). The essential difference is that, while the cavansite silicate sheet consists of a network of 4-fold and 8-fold rings of linked SiO_4 tetrahedra, the net in the new phase consists entirely of 6-fold rings. The latter has a simpler geometry which permits the layer to be folded at an angle of 72°40′ so that a 5-fold repetition of this process results in a nearly perfect prismatic structure corresponding to the 5 members of the multiple twin. No such mechanism can be imagined for cavansite, and, in fact, no twins are found.

The discovery of different borate polyanions in members of a series of borates having similar oxide formulas has been reported by J. A. Konnert, J. R. Clark, and C. L. Christ. The structures of macallisterite,[112] $MgO \cdot 3B_2O_3 \cdot 7.5H_2O$, of aksaite[113], $MgO \cdot 3B_2O_3 \cdot 5H_2O$, and of tunellite[114], $SrO \cdot 3B_2O_3 \cdot 4H_2O$ (by analogy, nobleite, $CaO \cdot 3B_2O_3 \cdot 4H_2O$), all contain a polyanion which, in isolated form as in macallisterite and aksaite, has the formula $[B_6O_7(OH)_6]^{2-}$. These polyanions share corners following Christ's fourth rule[115] to form the $[B_6O_9(OH)_2]^{2-}$ sheets of tunellite and nobleite. However, the structure of gowerite, $CaO \cdot 3B_2O_3 \cdot 5H_2O$, contains $[B_5O_8(OH)]^{2-}$ sheets plus isolated $B(OH)_3$ groups similar to those found in veatchite[116] and p-veatchite[117] both of which have the formula $4SrO \cdot 11B_2O_3 \cdot 7H_2O$. This discovery raises further questions about the chemical conditions that govern the crystallization of these various borates. Precise definition of these conditions might provide valuable information on the conditions causing formation of borate deposits.

[111] Frueh, A. J., Jr., and Golightly, J. P., 1967, The crystal structure of dawsonite, $NaAl(CO_3)(OH)_2$: Canadian Mineralogist, v. 9, p. 51–56.

[112] Dal Negro, Alberto, Sabelli, Cesare, and Ungaretti, Luciano, 1969, The crystal structure of macallisterite, $Mg_2[B_6O_7(OH)_6]_2 \cdot 9H_2O$: Accad. Naz. Lincei Atti, Cl. Sci. Fis. Mat. e Nat. Rend., v. 47, p. 353–364.

[113] Dal Negro, Alberto, Ungaretti, Luciano, and Sabelli, Cesare, 1971, The crystal structure of aksaite: Am. Mineralogist. [In press]

[114] Clark, J. R., 1964, The crystal structure of tunellite, $SrB_6O_9(OH)_2 \cdot 3H_2O$: Am. Mineralogist, v. 49, p. 1549–1568.

[115] Christ, C. L., 1960, Crystal chemistry and systematic classification of hydrated borate minerals: Am. Mineralogist, v. 45, p. 334–340.

[116] Clark, J. R., and Christ, C. L., 1968, Crystal structure of veatchite: Naturwissenschaften, v. 12, p. 648.

VOLCANIC ROCKS AND PROCESSES

Intrusive activity postdating the Mt. Aetna volcanic subsidence, Colorado

Field mapping by Priestley Toulmin III has shown that the Mount Antero Granite, known for its rich suite of beryllium minerals and miarolytic and pegmatitic segregations, postdates the volcanic subsidence structure centered around Mt. Aetna, Chaffee Co., Colo. A newly recognized stock of the granite apparently cuts through a dike that injects the boundary fault of the subsidence structure on the south flank of Mt. Aetna and is associated with molybdenite-bearing veins.

Middle Cenozoic andesitic volcanism of the western conterminous United States related to plate tectonics

Middle Cenozoic andesitic volcanism that predates initiation of basin-range structure in the Western United States has been interpreted by P. W. Lipman, H. J. Prostka, and R. L. Christiansen as indicating that until late Cenozoic time a spreading ridge system (the East Pacific Rise) was continuous west of North America, and a subduction zone was continuous along the western continental margin. Lower to middle Cenozoic andesitic and related rocks form two parallel belts in which the ratio K_2O:SiO_2 increases eastward. These belts are separated by a discontinuity from the northern Rocky Mountains to the western margin of the Colorado Plateau, but converge near the Canadian and Mexican borders. Analogy with Dickinson-Hatherton K_2O plots for modern island arcs suggests that early and middle Cenozoic subduction beneath the Western United States was along two subparallel imbricate zones that dipped about 20°E. The western zone emerged at the continental margin, but the eastern zone was entirely beneath the continental plate, partly coupled to the western zone below the low-velocity layer. These zones remained active in the southwestern United States through Oligocene time until disrupted by the late Cenozoic transform system; in the northwest the imbricate zones were replaced in early Oligocene time by a single steeply inclined zone that remained active until the late Quaternary.

[117] Gandymov, O., Rumanova, I. M., and Belov, N. V., 1968, Crystal structure of p-veatchite, $4SrO \cdot 11B_2O_3 \cdot 7H_2O = Sr_4B_{22}O_{34} \cdot 7H_2O = 2Sr_2[B_5O_8(OH)]_2 \cdot B(OH)_3 \cdot H_2O$ [in Russian]: Akad. Nauk SSSR Doklady, v. 180, p. 1216–1219.

Obsidian hydration dates in the Newberry Volcano area, Oregon

Irving Friedman, in cooperation with the Oregon Geological Survey, has determined by obsidian hydration analysis that rhyolite flows at Newberry Volcano, Oreg., range in age from about 300 to 6,000 yr. Pumice Cone appears to be 6,000 yr old, although an obsidian flow in the summit crater of the cone is 4,000 yr old. These dates are in contradiction with published dates of 1,720 yr for Pumice Cone based on the correlation of the cone with a pumice eruption, dated by the C^{14} method as 1,720 yr old.

Impact origin of cryptoexplosion structure at Decaturville, Mo.

Detailed mapping by T. W. Offield and H. A. Pohn at the Decaturville, Mo., cryptoexplosion structure indicates a very complex sequence of deformation involving circumferential and radial folds and normal faults, as well as inward and outward thrusts. These structures are believed to have formed penecontemporaneously and nearly instantaneously, accompanying the rise of a central dome and depression of a surrounding ring zone, after passage of a shock wave outward from the center of the circular structure. Shock pressures of about 50 kb are suggested by lamellae in quartz from rocks at least 1,200 feet below the probable focus of the event. Shock features and geometry of deformation indicate origin of the structure by impact. Fission-track determinations by C. W. Naeser of apatite in a tectonic inlier of Precambrian schist at the center of the structure suggest that the impact event occurred in Triassic time. Stratigraphic and geometric reconstructions of the disturbed rock section lead to the conclusion that the structure is nearly completely preserved rather than deeply eroded as was originally thought.

Sulfur probe for magmatic gases

Motoaki Sato developed a new electrochemical sulfur probe which is usable in magmatic gases up to about 800°C. This probe utilizes silver beta-alumina as the solid electrolyte, silver metal as the internal reference, and silver sulfide film as the sulfur-fugacity sensing element. The activity of silver in the sulfide film is controlled by the sulfur fugacity in the magmatic gas and gives rise to an electromotive force across the solid electrolyte cell. The probe was successfully tested by Sato and Priestley Toulmin III in holes drilled through the crust of the lava lake in Aloi Crater, Kilauea Volcano, Hawaii, in May 1970. The log f_{S_2} values obtained appear to follow the intrinsic f_{S_2} of pyrrhotite of composition, $Fe_{0.47}S_{0.53}$. The exact nature of the sulfur fugacity control is being examined.

Chemistry of deep-sea basalt

The continuing examination of dredge hauls from the Pacific, Atlantic, and Indian Oceans has emphasized to C. G. Engel that the dominant rock type is low-potassium, olivine-bearing basalt (oceanic tholeiite) and that some of these rocks are very similar in mineralogy and composition to some lunar rocks. The gabbros from the moon are higher in Fe and much lower in Na and K. Mineralogically the moon rocks might be called augite and (or) olivine-rich gabbros, whereas the rocks of the oceans are labradorite-rich gabbros and basalts.

Water content of submarine basalt

In a study of deep-sea pillow basalts dredged from the ocean floor, J. G. Moore (r0824) has found that vesicularity changes with composition as well as with depth. Alkalic basalts are more vesicular than tholeiitic basalts erupted at the same depth. These vesicularity data, when related to experimentally determined solubility of water in basalt, indicate that K-poor oceanic tholeiites originally contained about 0.25 percent water; Hawaiian tholeiites of intermediate K-content, about 0.5 percent water; and alkali-rich basalts, about 0.9 percent water. Analyses of fresh basalt pillows show a systematic increase of H_2O+ as the rocks become more alkalic. K-poor oceanic tholeiites contain 0.06 to 0.42 percent H_2O+; Hawaiian tholeiites, 0.31 to 0.60 percent H_2O+; and alkali-rich basalts, 0.49 to 0.98 percent H_2O+. The contents of K_2O, P_2O_5, F, and Cl increase directly with an increase in H_2O+ content such that at 1.0 weight percent H_2O+, K_2O is 1.58 percent, P_2O_5 is 0.55 percent, F is 0.07 percent, and Cl is 0.1 percent. The measured weight percent of deuterium on the rim of one Hawaiian pillow is −6.0 (relative to SMOW [118]); this value, which is similar to other indications of magmatic water, suggests that no appreciable sea water was absorbed by the pillow during or subsequent to eruption on the ocean floor.

Volcanic ash compaction—experimental simulation

H. R. Shaw devised a heating experiment to simulate the process of compaction in volcanic ash, using shards of asphalt. The rate of compaction of the asphalt due to its own weight was measured and compared with two simple theoretical models: (1) loss of porosity was assumed to be caused by flattening of discrete particles, and (2) pore space was assumed to shrink in the manner of collapsing bubbles in a liquid. The first model predicted compaction rates that fit the initial part of the experimental curve, and the second model predicted the observed form for the later stages of compaction. In combination the two models give a good description of the experimental results. Since the viscosity of the asphalt, as it would be measured in nonporous form, was a constant in the theoretical calculations, the results illustrate that the geometrical properties of the porous material are important controls on compaction rates. The advantage in this approach

[118] SMOW, standard mean ocean water.

is that the composite behavior can be integrated from relationships describing local deformations of the individual particles or of the cavities. This is simpler and gives more insight than theories based on bulk properties of the porous medium, because bulk properties are very complicated functions of the initial and deformed states. The results emphasize the importance of textural studies of ash flows.

Quantitative deformation of compacted ash-flow tuff

D. M. Ragan (Arizona State University) and M. F. Sheridan report that the orientation and shape of the two-dimensional strain ellipse produced by compactional deformation can be computed from the shape of deformed bubbles and three-pronged shards. The long axis of the ellipse parallels the foliation, and there is a close correspondence between the ratio of principal strains and bulk density. Single cooling units show a regular and continuous variation in strain with a ratio of 1.15 at the top and base and a maximum ratio of 2.4 in the lower middle section. Compactional strain around rigid inclusions produces a zone of pressure shadow at their sides. Elongate pumice lumps remain randomly oriented within the plane of compaction but rotate into this plane with increasing compaction.

Cenozoic volcanism in the Burney area, California

Field mapping by G. A. Macdonald in the Burney area, California, has revealed a sequence of volcanic and structural events during the Cenozoic. Andesite lava flows of possible late Pliocene age and one mass of rhyodacite were folded along nearly east-west axes and were block faulted. These rocks were buried by a series of volcanic rocks ranging in composition from basalt to dacite, and activity of this type has continued into historic time. Faulting continued through the early Pleistocene but ceased before the late Pleistocene.

Cyclic eruption pattern at Mount St. Helens, Wash.

Mount St. Helens is a Holocene composite andesitic volcano that has been vigorously active into the middle of the last century. The eruptive sequence established by C. A. Hopson indicates a cyclic eruption pattern. The cycles typically followed a progression from strong pyroclastic eruptions with deposition of airfall pumice to viscous protrusions (domes) and glowing avalanches to blocky lava flows, and from hornblende-pyroxene dacite to olivine-pyroxene andesite. Two such cycles began about 450 and 170 yr ago, and there is evidence for an earlier cycle that ended with olivine basalt flows about 500 yr ago. Each eruption cycle evidently represents the progressive tapping of a magma column that graded from more siliceous and volatile-rich at the top to more mafic and volatile-poor toward the bottom. Siliceous andesite was the primary magma; dacite, mafic andesite and basalt are interpreted to be differentiation products of the andesite.

Pearlette Ash Member of the Sappa Formation consists of at least two stratigraphic units

R. E. Wilcox and G. A. Izett have discovered that the Pearlette Ash Member of the Sappa Formation (Quaternary) of the central Great Plains, formerly used as a single stratigraphic marker, includes at least two and probably three ash falls of widely different age. The youngest, termed "Pearlette Ash type O", is present at many localities and is of special interest near Hartford, S.Dak., and on the Harrison-Monona County line in western Iowa, where it overlies glacial till of presumed Kansan age. Its source was a major rhyolitic eruption in Yellowstone Park, Wyo., K-Ar dated at 0.6 m.y. by J. D. Obradovich. An older ash bed, termed "Pearlette Ash type S", occurs at the type locality of the Sappa Formation in Harlan County, Nebr., and below till near David City and Coleridge, Nebr. Source of this ash was an eruption dated at 1.2 m.y., also in Yellowstone Park. The presence of these two ash beds (and the probable presence of a still older ash bed from a 2.0-m.y. Yellowstone eruption) emphasizes the need for a reexamination of those localities where the "Pearlette Ash" has been used as a marker of late Kansan age.

Geochemical factor analysis of rocks from Mule Ear diatreme, Utah

Factor analysis of covariance of metallic elements in the core rocks of the Mule Ear diatreme, San Juan County, Utah, has led R. A. Cadigan and D. E. Stuart-Alexander to conclude that the alteration of igneous rock components is the most important control on the distribution of these elements. Other geologic factors affecting the covariance of the elements are interpreted to be: contributions of components from assimilated sedimentary rocks, formation of reconstituted sedimentary dike rocks, contributions of ultrabasic igneous rock components, contributions of interstitial sulfate minerals, hydrothermal effects, and contributions of mica components.

Tertiary basalts in northern California

Field mapping by A. M. Hietanen in the Bucks Lake quadrangle, California, has shown that two petrologically different stratigraphic units of Tertiary basalt near the Feather River and its tributaries are correlative with the Lovejoy Basalt (Miocene) and the Pliocene high-alumina Warner Basalt of Russell[119] of northeastern California. Two-pyroxene andesites in the area were derived from the high-aluminum basalt magma through crystallization differentiation during which the magma was enriched in silicon, aluminum, and alkalies, and depleted in magnesium, iron, and calcium. This trend is

[119] Russell, R. J., 1928, Basin Range structure and stratigraphy of the Warner Range, northeastern California: California Univ. Dept. Geol. Sci. Bull., v. 17, no. 11, p. 387–496.

different from that found by Kuno in the segregation veins of the surface flows of the Warner Basalt in which iron is enriched and aluminum depleted.

Differentiation of basalt at Kilauea Volcano, Hawaii

T. L. Wright (r1943) and R. S. Fiske have outlined the important processes that control the chemical variation of basalt lavas erupted from Kilauea Volcano, Hawaii. These are (1) gravitative settling of olivine in summit reservoirs at depths of 2 to 4 km, (2) separation of liquid from crystals of augite, plagioclase, and ilmenite during crystallization in chambers within the east rift, and (3) fractionation of olivine, aluminous pyroxenes, and (or) plagioclase in conduits beneath Kilauea's summit at depths of 30 to 50 km. During eruption on the east rift, magmas produced by process 2 can be mixed with those affected by processes 1 and 3.

Giant slump breccias in Sierra Nevada metavolcanic rocks

Continued field mapping by O. T. Tobisch and R. S. Fiske in the Ritter Range pendant, Sierra Nevada, Calif., has disclosed that about 30 to 40 percent of the thick accumulation of geosynclinal volcanic rocks of Mesozoic age consists of chaotic mixtures of volcanic and hypabyssal clasts that float in a finer, generally pumiceous matrix. The smallest of these units is only 200 or 300 feet thick; the largest is 5,000 to 10,000 feet thick. This latter unit locally contains chunks of porphyritic felsite and dacite as large as 1,200 feet across. Each of these units is presumably related to volcanic events and catastrophic slumping that took place somewhere upslope.

PLUTONIC ROCKS AND MAGMATIC PROCESSES

Fluid inclusions from Ascension Island

Continued laboratory studies by E. W. Roedder [120] of inclusions in the granitic blocks from volcanic breccias of Ascension Island (originally described by Roedder and Coombs [121]) have provided data pertinent to several geological problems. The temperature of decrepitation of fluid inclusions on heating in the laboratory has long been used as a geothermometer. Some of the inclusions in quartz from the Ascension Island samples, however, did not decrepitate or even leak when held for 1 month at 100°C above their homogenization temperature. Conversely, the presence of (undecrepitated) inclusions in the feldspar of these same blocks places an upper limit on their temperature of eruption, as inclusions in feldspar decrepitate readily. The behavior of clear glass inclusions in these same blocks in various laboratory heating experiments yields further evidence on the crystallization temperatures and subsequent thermal history of these blocks.

[120] Roedder, E. W., 1970, Laboratory studies on inclusions in the minerals of Ascension Island granitic blocks, and their significance, *in* Problems of petrology and genetic mineralogy, V. S. Sobolev Memorial Volume II: Moscow, "Nauka" Publishing House, p. 247–258. [In Russian with English abstract]

[121] Roedder, E. W., and Coombs, D. S., 1967, Immiscibility in granitic melts, indicated by fluid inclusions in ejected granitic blocks from Ascension Island: Jour. Petrology, v. 8, p. 417–451.

Potassium-rubidium ratios in granitic rocks of central California

K-Rb ratios of granitic rocks of central California, studied by F. C. W. Dodge (r0600), B. P. Fabbi, and D. C. Ross, define two slightly different trends. The ratio is generally constant in rocks from near the San Andreas fault, whereas it tends to decrease slightly at high potassium contents in rocks from the central Sierra Nevada batholith. The ratios may be different owing to differences in water pressures that prevailed during formation of the respective rocks. Higher water pressures are thought to have prevailed during the final stages of crystallization of Sierra Nevada rocks, causing greater partial separation of potassium and rubidium between melts and aqueous phases and consequent deposition from rubidium-rich fluids during crystallization of late, high-potassium magmas. It is also conceivable that the differing behavior of the ratio may be due to late introduction of potassium feldspar into some rocks near the San Andreas fault.

The lack of systematic variation of the K-Rb ratio across the Sierra Nevada batholith, when compared with a recently advanced, experimentally based model for the origin of andesite, suggests that the westward decrease of potassium and rubidium contents is probably not attributable solely to magma generation along an easterly dipping Mesozoic subduction zone, at least at relatively shallow depths.

Stratiform ultramafic bodies accumulate

E. D. Jackson (r2507) has summarized experimental, theoretical, and field studies pertaining to stratiform intrusions, outlined the processes that form ultramafic cumulates, and evaluated the importance of these processes in space and time. He concludes that it is probable that many of the ultramafic rocks in older Precambrian shields are deformed stratiform intrusions, not alpine-type peridotites, and that cumulus processes were important in the formation of the earliest continental crusts. Furthermore, abundant cumulates have recently been described from rocks believed to be representative of oceanic crusts, and it seems likely that sill injection, fractional crystallization, and crystal settling all play an integral part in lower crustal formation at the midoceanic ridges. He finds the contention that the upper mantle itself consists of ultramafic rocks formed by crystal accumulation difficult to evaluate, but if so, he notes that penetrative deformation has obliterated almost all traces of cumulus textures and structures. Finally, he has identified undoubted cumulates among the returned lunar samples, and although the abundance of such rocks on the moon is unknown, it is apparent that cumulus processes have operated on magmas in the relatively weak lunar gravity field.

Five Mesozoic deformations revealed in walls of the Sierra Nevada batholith

In the central Sierra Nevada batholith, R. W. Kistler (r1579), J. F. Evernden, and H. R. Shaw show that the wall and roof rocks were folded in successive deformations of regional extent immediately preceding and, in part, contemporaneously with each of five episodes of Mesozoic granitic emplacement. The granitic rocks emplaced during each epoch of intrusion are localized in long linear belts identified by the following ages and trends: Late Triassic, N. 10° W.; Early Jurassic, N. 35° W.; Late Jurassic, N. 25° W.; Early Cretaceous, N. 10° W.; Late Cretaceous, N. 5° W. The strike of the axial surfaces of folds formed during each regional deformation is uniform over large areas and oriented about 20° farther to the northwest relative to the trend of the linear belt of penecontemporaneous intrusive rocks. This angle between the trends of time-related folds and linear belts of plutons is about the same as the angle found between the strike of active right-lateral faults and the trend of associated drag folds in California and elsewhere.

A first interpretation of the angular relations between the trends of fold axial surfaces and associated belts of granitic plutons in the central Sierra Nevada is that the folds formed as second-order drag folds related to right-lateral wrench movement in the crust above the developing intrusive bodies. Structures observed in wallrocks that imply lateral movements along the foothills fault system in the western Sierra Nevada support this interpretation.

Albitization, but not granitization, in eastern California

D. F. Crowder and D. C. Ross noted that two of the larger granitic masses in the northern White Mountains of California and Nevada characteristically have ragged and shredded dark minerals and strongly saussuritized plagioclase. There appears to be pervasive alteration (or metamorphism) that affects an area several tens of square miles in extent. Similar alteration was noted in associated metavolcanic wallrocks. The end product of this alteration seems to be rocks composed solely of chessboard albite and quartz which retain their original volcanic or granitic textures. Anderson[122] earlier noted this extensive albitization, but he considered it an accompanying effect of widespread granitization. Crowder and Ross suggested instead that the granitic rocks were intrusive, and along with their wallrocks, were intensely affected by some later intrusive event.

[122] Anderson, G. H., 1937, Granitization, albitization, and related phenomena in the northern Inyo Range of California-Nevada: Geol. Soc. America Bull., v. 48, p. 50.

Formation temperatures of carbonatites, Wet Mountains, Colo.

George Phair and N. L. Hickling have estimated the temperatures of formation of eight calcite-dolomite pairs from carbonatites of the Wet Mountains, Fremont and Custer Counties, Colo. The MgO content of the calcite was determined on three splits of each sample by precise, repetitive X-ray diffractometer measurement of the position of the $(\bar{2}11)$ line. The formation temperatures estimated from the solvus curve of Harker and Tuttle[123] average 350°±25°C, several hundred degrees below the minimum temperatures determined in laboratory studies of carbonatite melts. The low temperatures are consistent with structural, textural, and paragenetic evidence that these carbonatite bodies are hydrothermal replacements of mafic and ultramafic rocks. The results further substantiate qualitative temperature estimates on genetically related bodies of nearly pure potash feldspar which in turn have been interpreted as being genetically related to the formation of thorium deposits formed by outward secretion of thorium during potash metasomatism of CaO-poor granites.

Classification of peridotite and gabbro by late magmatic history

General recognition of several kinds of peridotite and gabbro, besides stratiform and true alpine, has led T. P. Thayer[124] to propose that they be classified as authigenic, polygenic, or allogenic, depending on their late magmatic history. Rocks which, like those in stratiform complexes, differentiated and crystallized in situ are authigenic; rocks which differentiated and crystallized in one place and moved elsewhere by rheid flowage, as true alpine peridotites are believed to have moved, are classed as allogenic. The polygenic rocks have differentiated and crystallized at various times and places: the nickel sulfide-bearing peridotites of the Thompson (Canada) and Kambalda (Western Australia) type, and composite intrusions like the Duluth Gabbro Complex, exemplify the variety of rocks in this class. Magmatic ore deposits are shown to be controlled by the late magmatic history of their host, especially by processes affecting gravitational settling of crystals or immiscible sulfides. Because magmatic ore deposits and petrologic features of their host rocks are genetically related, recognition of diagnostic features in the field can effectively guide prospecting. Allogenic peridotites, for example, have not been found to contain significant nickel sulfide deposits.

[123] Harker, R. I. and Tuttle, O. F., 1955, Studies in the system $CaO\text{-}MgO\text{-}CO_2$–Part 2, Limits of solid solution along the binary join $CaCO_3\text{-}MgCO_3$: Am. Jour. Sci., v. 253, p. 274–282.

[124] Thayer, T. P., 1971, Authigenic, polygenic, and allogenic ultramafic and gabbroic rocks as hosts for magmatic ore deposits: Geol. Soc. Australia Spec. Pub. 3, [In press]

Anatexis simulation experiments

R. T. Helz found that melt compositions produced by equilibrium partial melting of two tholeiites (one quartz-normative, one olivine-normative) at 5 kb water pressure and at oxygen fugacities defined by the quartz-fayalite-magnetite buffer are andesitelike at 900° to 1,000°C. The residual melt compositions (10–15 percent by volume) produced at 725° to 750°C project (from anorthite) near the orthoclase-quartz eutectic, rather than near the granite minimum in the albite-orthoclase-quartz system. This observation is compatible with the available phase-equilibria studies in the anorthite-albite-orthoclase-quartz system and with some other anatexis experiments. This displacement from the minimum melting trough of the albite-orthoclase-quartz system is characteristic of melts coexisting with calcic plagioclase.

METAMORPHIC ROCKS AND PROCESSES

Distribution and age of high-grade blueschists, associated eclogites, and amphibolites from Oregon and California

R. G. Coleman and M. A. Lanphere studied isolated blocks of high-grade blueschist and amphibolite facies metamorphic rocks occurring within the Jurassic and Cretaceous eugeosynclinal deposits of the Coast Ranges of southwestern Oregon and California. The blocks range in size from individual rock masses commonly 5 to 1,000 feet in diameter to a few larger masses as much as 7 mi long and 2 mi wide. The high-grade blocks are predominantly basaltic in composition and include glaucophane schists, eclogites, and gneissic rocks of the amphibolite facies. Field relationships indicate that the blocks are closely associated with serpentine, that high-grade blueschist and amphibolite blocks, lower grade blueschists, volcanic rocks, and cherts occupy disturbed zones that may be related to thrusting, and that there is no exposed in situ provenance for the high-grade blueschists, eclogites, and amphibolites. Potassium-argon mineral ages of white mica and actinolite from the blueschists and of hornblende from the amphibolites indicate that these minerals crystallized approximately 150 m.y. ago, but the ages measured on glaucophane from the blueschist blocks are commonly younger. These data suggest that the high-grade blueschist and amphibolite blocks represent fragments of a cryptic metamorphic terrane of pre-Tithonian age that were tectonically mixed with younger rocks of the Franciscan Formation in California and Otter Point Formation in Oregon. The younger ages for glaucophane probably reflect metamorphic episodes in which lower grade in situ blueschist facies mineral assemblages were developed in the blocks after their emplacement within the Franciscan Formation.

Late Triassic metamorphism in the northern Okanogan highlands

Studies in northern Okanogan County, Wash., by C. D. Rinehart and K. F. Fox, Jr., show that rocks as young as Late Triassic are involved in at least two episodes of regional metamorphism recognized in that region. The earlier, more intense episode is represented by a metamorphic grade typically in the amphibolite facies along the east flank of the Okanogan Range; a few miles eastward the grade declines to greenschist facies. The oldest pluton thus far isotopically dated in the region lies at the east margin of the Okanogan Range. It is late Triassic in age, but it is not metamorphosed. Hence the main regional metamorphic episode must have occurred during the latest Triassic. A later episode of low-grade metamorphism of unknown areal extent is represented by weakly recrystallized greenstones which unconformably overlie Triassic(?) rocks of biotite grade within the greenschist facies. The age of the greenstone and the younger metamorphism is loosely bracketed as post-Triassic(?)–pre-Eocene.

Electron microprobe studies of minerals from the Taconic allochthon

E-an Zen, together with A. E. Bence (State University of New York at Stony Brook), is conducting an electron microprobe study of coexisting minerals from the Taconic allochthon and surrounding autochthon. The minerals show the following order of progressive iron enrichment: garnet (almandine rich) > staurolite > hornblende > chloritoid > biotite > chlorite. The data restrict the topologic types of AFM diagrams for the progressive metamorphism of pelitic schists from southwestern New England (Massachusetts, Connecticut, and adjacent New York). Biotite and chloritoid coexist in very lime-poor rocks; garnet occurs only in rocks of higher lime concentration; consequently, it does not belong to the traditional AFM projection. At still higher lime content, hornblende is present. Hornblende and chloritoid should be stable in restricted compositional ranges, but no example has been found to date. Muscovite and especially biotite are alkali deficient. Muscovite is not a simple homogeneous phase in most of the samples studied; many samples seem to have two muscovites present, one more phengitic than the other. Ilmenite shows compositional variations mainly in manganese content reflecting its textural relation to garnet (high Mn in Mn-rich garnet cores). Most of the garnets show a tendency to zone in the classic manner (Mn-rich core, Fe-rich rim), but other iron-magnesium bearing minerals show no such zoning. Albite-rich plagioclase is zoned, some progressively enriched in calcium at the rim (in medium to high grade of metamorphism) and some which show a reversal to pure albite rims (in retrograded, polymetamorphic zones). No evidence has been found for the peristerite gap in the plagioclase series.

Prehnite-pumpellyite facies of regional metamorphism in the western Appalachians

E-an Zen reports that pumpellyite-bearing metabasalts and metagabbros are found in the Rensselaer plateau area in New York at Babcock Lake (BL) and Turner Mountain (TM), within the allochthonous Rensselaer Graywacke, as well as in a metabasalt from Bunker Hill, Jonestown, Pa. (J). Assemblages found include: (BL), chlorite-pumpellyite-epidote-hematite; (TM), actinolite-chlorite-stilpnomelane-epidote, and chlorite-pumpellyite-stilpnomelane-epidote; (J), actinolite-chlorite-pumpellyite-stilpnomelane, chlorite-prehnite-pumpellyite, hematite-chlorite-pumpellyite-epidote, and prehnite-pumpellyite-calcite-chlorite. All the assemblages listed include quartz, white mica, albite, and a clay mineral, probably vermiculite. After partial analyses were made with an electron microprobe, it was possible to calculate, by a knowledge of the chemography, the locations of the various assemblages on P_t-T, $P_s-a_{H_2O}$, and $a_{O_2}-a_{H_2O}$ projections. In this way the relative metamorphic grades of these rocks were determined. The hierarchy of metamorphism thus determined is in excellent agreement with field observations on the nature of the surrounding rocks and on their metamorphism. The presence of clay minerals and calcite with pumpellyite and prehnite should caution against a hasty erection of a metamorphic facies such as the "clay carbonate facies" as opposed to "prehnite-pumpellyite facies."

SEDIMENTARY ROCKS AND DIAGENETIC PROCESSES

Fossil deuterium in deep-sea cores

Irving Friedman analysed the deuterium (H^2) content of 100 water samples squeezed out of sediments that were collected during the JOIDES deep-sea core drilling, legs 4 and 5. Because evaporation results in snow and glacial ice being depleted in deuterium and the remaining ocean water being enriched in deuterium, Friedman suggests that the deuterium analyses, combined with accurate dating of the sediments, could permit estimation of the amount of glacial ice on the continents at different times in the past. Preliminary results show that the oceans have changed about 1.5 percent in deuterium concentration from early Tertiary (Eocene) to Holocene. On the basis of these data, Friedman suggests that a significant part of the earth was covered with ice during the Eocene as well as during the Pleistocene Epochs, whereas data from Miocene sediments indicate little ice cover.

Evaporite deposition by mixing of brines

O. B. Raup found that, in experiments using artificial and sea-water brines, halite and sylvite can be precipitated by mixing brines of differing stages of evaporation. Three sets of experiments were made using both artificial and sea-water brines as follows: (1) magnesium chloride and sodium chloride, (2) magnesium chloride and concentrated sea water, and (3) two sea-water brines, each evaporated to a different concentration. The mixing of two brines, one rich in magnesium chloride and another rich in either sodium or potassium chloride, results in a solution supersaturated with either sodium or potassium chloride, and these salts precipitate fairly rapidly.

These experimental results can be explained by the well-known fact that magnesium chloride significantly lowers the solubility of both sodium chloride and potassium chloride in aqueous solutions, and that magnesium chloride is enriched in sea water by progressive evaporation. Thus when sea-water brines rich in magnesium chloride are mixed with brines at or near saturation for sodium and potassium chloride, halite, possibly accompanied by sylvite, is precipitated. Raup therefore concludes that (1) salt could precipitate in a marine evaporite basin by mixing brines of different composition and specific gravity, (2) precipitation might occur without further water loss by evaporation, (3) precipitation could take place from brines that were undersaturated before mixing, (4) brine mixing would cause the most salt to be deposited in the deepest parts of a basin, although virtually all parts of the basin could receive such deposits, (5) sylvite could be precipitated as a primary mineral, and (6) hopper crystals (cubic and tabular) could form as a result of brine mixing in water of any depth.

Boron in authigenic minerals

R. A. Sheppard and A. J. Gude III studied zeolites and potassium feldspar from lacustrine tuffs of the Barstow Formation (Miocene), Mud Hills, Calif. (San Bernardino County), and of an unnamed Pliocene deposit near Wikieup, Ariz. (Mohave County). They found by semiquantitative spectrographic analysis that the zeolites show 0 to 300 ppm of boron (mostly $<$ 50 ppm, but especially low in analcime and chabazite), but the authigenic potassium feldspar shows 700 to 5,000 ppm (mostly $>$ 1,000 ppm) of boron. High-boron feldspars show aluminum deficiency, suggesting boron substitution for aluminum. These feldspars display distortion of cell parameters comparable with the distortions observed by R. F. Martin (McGill University) on synthetic boron-bearing potassium feldspars.

Elemental sulfur in diagenesis

Elemental sulfur is one of the clearest indicators of early diagenesis in the upper few feet of estaurine sediment in Choctawhatchee Bay, Fla., according to studies by J. G. Palacas and A. H. Love. The content of elemental sulfur decreases markedly with depth of burial of the sediment. With increasing depth the elemental sulfur probably combines with unstable FeS (hydrotroilite) to form stable FeS_2 (pyrite). The elemental sulfur probably is derived mostly as an oxidation product of dissolved sulfides, chiefly unstable black FeS and H_2S. The sulfides themselves are a product of bacterial reduction of sulfate-sulfur found in overlying and interstitial waters.

Methods of handling the samples in the field and laboratory make a considerable difference in the amount of elemental sulfur extracted. Air-dried (oxidized) samples yielded an average of about three times as much elemental sulfur as freeze-dried (nonoxidized) samples.

Magnesia- and silica-rich gels and crystalline silica hydrate in nature

R. A. Sheppard and A. J. Gude III, working near the east fork of the Trinity River in Trinity County, Calif., discovered a small chemically precipitated delta of magnesium silicate gel where the alkaline and saline spring water enters a creek. The spring water shows a high silica content (500–800 ppm) but not a high magnesia content (0.2 ppm). Thus the gel seems to be a sink for magnesium, extracting the small amount out of solution. This observation suggests a mechanism for the diagenetic formation of sepiolite in lacustrine sediments as the result of alteration magnesium silicate gels formed where magnesium-bearing stream water discharges into alkaline, saline lakes. Gude reported the discovery from the same area of silhydrite, a mineral having the composition $3\,SiO_2 \cdot H_2O$, in its first natural occurrence, in close association with magadiite.

Nature of organic matter in fluid inclusions

E. W. Roedder and K. A. Kvenvolden (NASA, Ames Research Center) found that quartz crystals from calcite veins in Precambrian metasedimentary rocks in southwest Africa contain primary and secondary inclusions of organic fluids. The organic fluids are dominantly *n*-alkanes (ranging at least from n-C_{10} to n-C_{33}) and unusually high concentrations of isoprenoid hydrocarbons (from C_{14} to C_{20}, with C_{17} least abundant). The molecular composition and distribution of the hydrocarbons strongly suggest a biological origin for these components rather than as abiogenic magmatic condensates as has been previously thought. The Precambrian rocks are probably more than 2.6 b.y. old, but the ages of both the vein and the inclusions are unknown; they could be much younger.

Geochemistry of sandstone authigenesis and hydrothermal alteration

J. D. Vine (r2255) and E. B. Tourtelot found that lower Eocene sandstones and mudstones from parts of Wyoming, Colorado, Utah, New Mexico, and Montana show pronounced etching and alteration of the detrital grains and formation of authigenic minerals. The rocks are arkose and graywacke derived from Precambrian crystalline rocks, and carbonate and quartz sandstones derived from Phanerozoic thrust belts. The authigenic minerals include carbonates, zeolites, clay minerals, and locally epidote and amphibole. Much of the observed alteration was probably accomplished by alkaline ground water. Amphibole-bearing, hydrothermally altered rocks in the Bearpaw Mountains, Mont., seem to be enriched in minor elements, whereas zeolite (laumontite)-bearing hydrothermally altered rocks in the Spanish Peak area of Colorado (see U.S. Geol. Survey, r0632, p. A127) appear to be depleted of minor elements. Unoxidized, green-tinted sandstones are relatively enriched in minor elements relative to red, orange, or yellow tinted sandstones that are presumed to be more highly oxidized. Data pertaining to the distribution of minor elements may be useful in the search for mineral deposits such as uranium in sedimentary rocks.

GEOCHEMISTRY OF WATER

Geochemistry of the California Coast Ranges

Ivan Barnes and B. J. Rapp reported that systematic sampling and analysis of natural fluids indicate that the California Coast Range fault is a geochemical boundary. To the east, in the Great Valley province, are found waters notably rich in chloride. Along the fault mixed chloride-bicarbonate waters are found in part in association with mercury deposits. The coastal province to the west of the Coast Range fault is characterized by bicarbonate-rich fluids of low chloride content. The bicarbonate probably is a product of present day metamorphism.

Serpentinization not only involves locally derived meteoric water but also chloride-rich waters of the Great Valley sequence. A chloride-rich water, chemically unlike the calcium hydroxide waters earlier ascribed to serpentinization, is thermodynamically identical in terms of reaction states. As shown by J. R. O'Neil, the chloride-rich water is isotopically much heavier than the calcium hydroxide waters. The spring yields a precipitate identified by R. W. Luce as being part brucite. There is no evidence that the serpentinization by the chloride water is a hydrothermal reaction.

Iron in water of the Chicot aquifer, Louisiana

The extensive Chicot aquifer underlies most of southwestern Louisiana and is heavily used as a source of water for agricultural, industrial, and domestic purposes. According to L. D. Fayard (p. D182–D186) a major problem associated with the use of water from the Chicot aquifer is the generally high iron values, which range from a few tenths of a milligram per liter to 15 mg/l in some areas.

A study of the relation between Eh, pH, and iron concentration showed that the iron in solution is in equilibrium with ferric hydroxide and not with hematite or magnetite. Measured oxidation potentials range from +50 to +110 mv and agree with the values predicted for equilibrium with ferric hydroxide on the basis of determined iron concentrations.

Weathering of serpentine in a small watershed in Maryland

Precipitation input and stream discharge of dissolved minerals have been measured over a period of one year for a 57-ha watershed at Soldier's Delight, Md. E. T. Cleaves (Maryland Geological Survey), D. W. Fisher (USGS), and Owen Bricker (The Johns Hopkins University) found that serpentine minerals in the watershed are the principal weathering species. In the stream draining this watershed, base-flow concentrations of magnesium exceed 40 mg/l, and dissolved-silica levels at times reach 25 mg/l. The stream water is predominantly magnesium bicarbonate–sulfate, with a mole ratio of about 3 bicarbonate to 1 sulfate. However, virtually all the stream sulfate is supplied in rain and snow, and not by dissolution of minerals in the watershed. Total annual loads of sulfate in precipitation and in stream discharge amount to about 45 kg/ha. Deposition in precipitation and removal by the stream are also approximately equal for calcium and chloride. Loads of these solutes are each about 5 kg/ha per yr. Potassium is accumulating in the watershed, as evidenced by an excess of deposition over discharge of this element. Additions of sodium and phosphate also slightly exceed the stream removal of these constituents; quantitative estimates of the rates of accumulation are not feasible from data for a single annual cycle. Considerable quantities of nitrate (23 kg/ha), ammonium (5 kg/ha), and hydrogen ions (nearly 1 kg/ha) were deposited by rain and snow in the course of a year. Hydrogen ions are almost completely removed by neutralization reactions with watershed minerals. A small fraction of the input fixed nitrogen is carried out of the watershed in the stream; the remainder is probably removed by biological processes and returned to the atmosphere as elemental nitrogen or as gaseous nitrogen compounds.

Studies of aluminum hydroxide crystallization processes

When solutions containing small amounts of dissolved aluminum are partly neutralized (pH 4.5 to 6.5) a part of the material formed is a polymeric dissolved complex aluminum hydroxide ion which slowly grows to the crystalline form of gibbsite and attains solid-state chemical behavior. Studies by R. W. Smith and J. D. Hem of the behavior of this material show that solid-state behavior is attained when the units become larger than the range $Al_{100}(OH)_{273}{}^{+27}$ to $Al_{400}(OH)_{1150}{}^{+50}$. The rate of conversion of the polymer to a solid is pH dependent, and the process may take from 3 months to more than a year to reach 90-percent completion at 25°C. Slower rates of conversion occur in the more acid solutions.

Interaction of mineral matter and water in saline environments

A computer program developed by B. F. Jones and A. H. Truesdell for distribution of solute species from analysis of natural waters has been extended to include calculations for over 80 species, and computations of ion activity products for nearly 70 minerals. Complete application of the procedures requires further testing, but they include calculation of aqueous carbon, sulfur and nitrogen gas species from Eh and pH measurement, plus total constituent values.

Analysis by B. F. Jones of the alkaline lacustrine sediment from Abert Lake, Oreg., suggests that the authigenic mixed-layer clay mineral dominating the mud has been derived principally from reactions of alkaline water with volcanic glass and fine-grained pyroxene. Although magnesium and silica are obtained through solution, alumina and iron are transported through inorganic or chelated colloids.

R. L. Hay (University of California, Berkeley) and B. F. Jones (USGS) studied basaltic ash on Hawaii as a function of age and climate. Interstitial-water analyses have supplemented petrographic data and bulk-chemical analyses of fresh and altered materials to describe the weathering process as coupled dissolution of glass and primary silicates with precipitation of secondary minerals. Silica and major cations are leached at nonconstant rates in ratios ranging from 2:1 in regions of highest rainfall to 1:3 in drier areas.

B. F. Jones reported that chemical and X-ray analysis of fine sediment, plus pore-fluid data, from the deepest part of the Somes Sound fjord, Mount Desert Island, Maine, showed little evidence of silicate-mineral alteration in highly anoxic marine muds.

Chemistry of pore fluids in marine sediments

Analyses of chemical constituents in pore fluids have been completed for all drill holes in the Deep Sea Drilling Program for the Atlantic and Pacific Oceans. The project of squeezing out and evaluating pore fluids from the deep drill cores has been conducted by F. T. Manheim (USGS) together with K. M. Chan and, later, F. L. Sayles (Woods Hole Oceanographic Institution).

Although sodium and chloride concentrations in pore fluids remain remarkably constant throughout cores from as deep as 1,000 m below the sea floor and as old as Late Jurassic, other constituents, especially potassium, calcium, magnesium, sulfate, bicarbonate, strontium, and manganese vary markedly. Fluids from rapidly deposited biogenic oozes (carbonate rich) demonstrate strong enrichments in calcium and strontium, and depletions in magnesium compared with standard sea water, Ca and Sr being enriched to 1.5 g/kg and 130 ppm, respectively. In contrast, fluids from rapidly deposited clayey sequences show depletion in calcium and potassium, with very strong depletion in magnesium and sulfate. Fluids from slowly deposited pelagic sediments show moderate depletions in magnesium and sulfate, with a net enrichment in potassium. Where salt plugs or evaporite sediments occur beneath the sea floor, marked chloride and salinity increases occur in the pore fluids. These and other evidences prove that diffusion of salts proceeds readily through marine sediments to the maximum depths penetrated. Such increases in salt concentration can be used as guides to the presence of evaporites well below (ahead of) the drill.

Geochemistry of the National Reactor Testing Station, Idaho

Geochemical analysis by Robert Schoen of the ground and surface waters in the vicinity of the National Reactor Testing Station, Idaho, indicated that recharge from two identifiable sources coalesces in the underlying basalt of the Snake River Group. Water containing major proportions of calcium, magnesium, and bicarbonate enters the basalt aquifer from mountainous areas to the northwest that consist dominantly of Paleozoic carbonate rocks. Significant amounts of sodium, silica, and fluoride characterize waters that enter the basalt to the northeast near Yellowstone Park in a region dominated by outcrops of silicic volcanic rocks.

ISOTOPE AND NUCLEAR GEOCHEMISTRY

ISOTOPE TRACER STUDIES

The Troodos massif, Cyprus—exposed oceanic crust and upper mantle?

The Troodos ophiolites of Cyprus consist of basement ultramafic rocks overlain by gabbros which have been intruded by an extensive system of diabase dikes that extend upward into overlying pillow lavas. Previous work[125] suggested that the massif may be a segment of oceanic crust and upper mantle which was exposed by overthrusting of the Eurasian plate by the African plate during the Alpine orogeny. In the present study by Z. E. Peterman, R. G. Coleman, and R. A. Hildreth (p. D157–D161), rubidium and strontium contents and strontium isotopic compositions were determined on 10 samples of gabbro, diabase, pillow lava, and quartz diorite (trondhjemite) to compare these rocks with young ocean-ridge tholeiites that are now being generated at the site of the plate formation. Although the rubidium and strontium contents of the Troodos rocks are similar to those of modern ocean-ridge tholeiites, the Sr^{87}– Sr^{86} ratios are significantly higher (0.7040–0.7057) and may be compared with Sr^{87}-Sr^{86} ratios of 0.7012 to 0.7035 for modern ocean-ridge tholeiites from the Mid-Atlantic Ridge and the East Pacific Rise. If the Troodos massif is really oceanic crust, these data suggest that partial melting in the sub-Tethys mantle supplied basaltic liquids to the ridge system which were significantly more radiogenic than those forming along the more recent ocean ridges.

[125] Gass, I. G., 1968, Is the Troodos Massif of Cyprus a fragment of Mesozoic ocean floor?: Nature, v. 220, p. 39–42.

Correlation of Sr^{87}/Sr^{86} in oceanic basalts with large cation elements

During the past year a considerable number of strontium isotopic analyses have been made by C. E. Hedge and Z. E. Peterman on suites of volcanic rocks from Samoa, Tahiti, Guadalupe, San Felix, Easter, and the Galapagos Islands, all in the Pacific Ocean.[126] Sr^{87}/Sr^{86} values of basalts range from a low of 0.7019 for a sample from the Galapagos Islands to a high of 0.7066 for a sample from Samoa. These and earlier data strongly confirm a correlation between Sr^{87}/Sr^{86} and certain chemical features of the rock. Oceanic basalts with low Sr^{87}/Sr^{86} values are relatively poor in potassium, rubidium, barium, and other large cations, and, conversely, basalts with high Sr^{87}/Sr^{86} values are relatively enriched in these elements. This pattern seems to indicate that the mantle is continually undergoing removal of these elements by volcanism and that the low Sr^{87}/Sr^{86} values reflect a past depletion within that particular mantle material from which the basalt was derived.

The source of lead in southeast Missouri galena ores

A lead isotope study was made on ores and cryptic lead in rocks from southeast Missouri by B. R. Doe and M. H. Delevaux to ascertain the source of this metal in the major galena deposits of the area. The results of the study indicate that all the lead could have been derived from the Lamotte Sandstone, an aquifer unit which underlies the Bonneterre Dolomite, the host rock of the ore. The Precambrian basement, the dolomitic and calcareous limestones of the Bonneterre Dolomite, and the calcareous shales of the overlying Davis Formation appear not to be a major source of lead in the ores. All the lead produced from the old Mineral Belt district could have been concentrated from about 11,000 sq mi of the Lamotte Formation.

STABLE ISOTOPES

Deuterium in snow cores—a climatic indicator

The use of deuterium in snow cores as a climatic indicator is suggested by the results obtained by Irving Friedman (r0068) and G. I. Smith on 20 snow cores obtained in the Sierra Nevada in April 1969 and at the same sites in April 1970. Snow in all the 1970 cores was enriched in deuterium by

[126] Some of these and other isotopic data have been reported by Peterman (r1169) and Hedge.

approximately 20‰ as compared to snow collected from the same sites collected in 1969. The snowfall in 1968–69 was three times normal, whereas that in 1969–70 was slightly below normal. The depletion of deuterium in the abnormally high snowfall year is ascribed to a higher than usual incidence of air-mass trajectories from the north during this snow year. The data suggest that glacial periods in the region of the Sierra Nevada would be characterized by a higher incidence of such northern trajectories rather than a higher frequency of the usual storms from the central and equatorial Pacific.

Origin of East African cherts

It is now established that cherts associated with saline lakes form from the sodium silicate precursors, magadiite and kenyaite. J. R. O'Neil (USGS) and R. L. Hay (University of California, Berkeley) have found that the O^{18}/O^{16} values of the East African cherts correlate very well with geologically inferred salinities of their associated lakes. In fact, the cherts from drill core B of Lake Magadi have the highest O^{18}/O^{16} values of any terrestrial substances (δ=+44.1). These data suggest solution of the precursor and precipitation of quartz in the brine and argue against leaching of the precursor by ground water to form silica as proposed by H. P. Eugster (Johns Hopkins University).

Sulfur isotope study of the Darwin deposits, California

R. O. Rye and W. E. Hall have studied the distribution of sulfur isotopes in the Darwin Ag-Pb-Zn deposits, in southern California. The δS^{34} values of all minerals range from 4.4‰ to -5.7‰. For a given sulfide assemblage, however, the enrichment of S^{34} is always iron sulfide > sphalerite > galena, and the differences in δS^{34} values of coexisting sphalerite and galena are very consistent with an average difference of about 2.0‰. This indicates that galena and sphalerite were nearly always depositing in equilibrium and at temperatures averaging about 330°C. The differences in δS^{34} values of iron sulfides, galena, and sphalerite also indicate that approximate equilibrium was usually obtained in the entire sulfide assemblage. The actual δS^{34} value of the sulfides depends upon whether pyrite or pyrrhotite is the dominant iron sulfide. When pyrite is the dominant iron sulfide, the δS^{34} values of all minerals are positive. When pyrrhotite is dominant, the δS^{34} values are negative. The data indicate that the δS^{34} of the total sulfur in the hydrothermal solutions was close to 0‰. The fairly wide range of δS^{34} values in galena and sphalerite probably reflects the variations in the P_{O_2} and pH of the hydrothermal fluids that resulted in the deposition of pyrrhotite instead of pyrite in certain areas of the mine. Such possible variations are consistent with geological observations.

C^{13}-C^{12} ratios of CO_2 from Hawaiian lava lake

Ten days after eruption and the filling of Aloi crater in Kilauea, holes were drilled through the thin crust to the lava. Irving Friedman collected several samples of the CO_2 given off by the cooling lava by pumping the gases (mainly SO_2 and H_2O?) through $SrCl_2$ solution. The $SrCO_3$ precipitates were then used for δC^{13} analyses. The δC^{13} values were approximately -15‰ PDB,[127] a value which is significantly lighter than the value of 0.6‰ measured in liquid CO_2 inclusions in Hawaiian olivine nodules by J. R. O'Neil. These measurements bear on the perplexing problem of the carbon isotope geochemistry of igneous rocks.

Chemical and isotopic analyses of the Climax deposits, Colorado

Seven samples of quartz molybdenite ore and late-stage fluorite from the Climax mine, Colorado, were crushed in vacuum for isotopic and chemical analyses of fluid inclusions by W. E. Hall and Irving Friedman. The δD (SMOW)[118] values of the fluid inclusions ranged from -87‰ to -138‰, and the salinities ranged from approximately 10,000 to 300,000 ppm, low salinities being associated with low deuterium contents. Thus the ore-depositing fluid ranged in origin from dominantly magmatic hydrothermal initially to dominantly unaltered meteoric water in late-stage mineralization.

J. D. Gleason and Irving Friedman have measured the O^{18} content of quartz in the veins and observed a depletion in O^{18} with distance from the center of mineralization. This is opposite to the direction expected with a temperature decrease and may be correlated with an increase in amount of isotopically light meteoric water in the ore fluid.

ADVANCES IN GEOCHRONOMETRY

Significance of zircon ages in the Boulder Creek batholith, Colorado

T. W. Stern and M. F. Newell obtained isotopic ages on six zircon samples from the Boulder Creek Granite and one zircon sample from a dike of Silver Plume Granite (Jefferson, Boulder and Gilpin Counties, Colo.). In addition, Stern determined lead-alpha ages of 32 samples of Boulder Creek zircon and of 3 samples of Silver Plume zircon. George Phair and David Gottfried selected the rocks used in the study from a suite of more than 250 medium to large samples of Boulder Creek Granite collected over a 10-year period. A preliminary lead-alpha reconnaissance tied to a detailed petrological and geochemical sampling map of the batholith was useful in screening samples for the more accurate but time-consuming and expensive isotopic determinations. In addition, the lead-alpha results made possible interpolation between isotopic "fixed points" when all Pb^{206}/U^{238} and lead-alpha ages were plotted on a map of the batholith.

[127]PDB, Pee Dee Belemnite standard.

Results of the isotopic analyses of the six Boulder Creek samples closely fit a discordia curve having an upper intersection indicative of emplacement 1,725 m.y. ago. Results of the isotopic analyses of the one Silver Plume sample, coupled with analyses by members of the Carnegie Institution of three samples from the region immediately to the north of the batholith, yielded a discordia curve indicative of emplacement 1,415 m.y. ago. This age of emplacement is very close to that obtained on well-crystallized uraninite from a pegmatitic correlative of Silver Plume Granite in the Central City district a few miles to the southwest of the batholith. The separate discordia curves for the Boulder Creek and Silver Plume Granites converge near their lower intercepts with the concordia curve and indicate that major episodic lead loss took place in both zircon suites 45 to 65 m.y. ago.

The pattern of isochrons as plotted on the map define a reduced age aureole in those parts of the Boulder Creek Granite and nearby Silver Plume Granite that adjoin a 77-m.y. hornblende granodiorite stock at Jamestown, Colo. The aureole in the Boulder Creek batholith appears to widen along such breccia reefs (profound northwesterly trending faults) as are cut by the Laramide stock; these reefs are believed to have served as conduits for warm solutions, the agent of recrystallization of the zircon. Grain counting showed that the frequency of clear, colorless zircon rims on older, deeply colored, more metamict cores was inversely related, represented with a smooth curve, to the measured discordant Pb^{206}/U^{238} age of the Boulder Creek samples. The presence of widely variable proportions of inherited metamorphic zircon in the isotopically analyzed samples introduced no significant differences in the measured emplacement ages. This result is compatible with the field observation that intrusion of the syntectonic Boulder Creek Granite took place during a period of major regional metamorphism.

Ar^{40}/Ar^{39} dating

M. A. Lanphere and G. B. Dalrymple have determined K-Ar ages by the Ar^{40}/Ar^{39} technique on a variety of terrestrial materials, including biotite, muscovite, hornblende, alunite, feldspar, and basalt, whose conventional (isotope-dilution) K-Ar ages range from 3.4 m.y. to nearly 1,700 m.y. The samples were irradiated with fast neutrons for 40 Mwh (4×10^{18} nvt)[128] in the U.S. Geological Survey 1-MW TRIGA reactor to induce the reaction $K^{39}(n, p)\ Ar^{39}$. Corrections for interfering argon isotopes produced by neutron interactions with calcium and potassium were determined by measuring the argon isotopes in irradiated CaF_2 and K_2SO_4. For all the samples studied, the K-Ar ages determined by this technique are in satisfactory agreement with those determined by the conventional isotope-dilution technique. The results indicate that the Ar^{40}/Ar^{39} technique has about the same range of applicability as the conventional technique, even for materials with high calcium content such as hornblende and basalt. This technique has several important advantages over the conventional technique: (1) potassium and argon are measured on the same sample, thus eliminating the effects of sample inhomogeneity; (2) because the age is calculated from the Ar^{40}-Ar^{39} ratio, absolute abundances of potassium and argon are not needed, and the method is potentially more precise; and (3) the method can be used on very small samples.

In addition to the total fusion experiments described above, experiments involving incremental heating of irradiated samples of four different minerals were made to find out if the age of crystallization of rocks that have experienced postcrystallization heating could be determined. Results for biotite and potassium feldspar from granite of the Marble Mountains, Calif., indicate approximate plateaus for age–Ar^{39} release diagrams indicate an age greater than conventional K-Ar ages for these materials but less than the true age of the rock determined by U-Pb and Rb-Sr methods. Muscovite and hornblende from the World Beater Porphyry of Murphy[129] in California, yield complex argon release curves, and one of the gas fractions gave an age as high as the true age of the rocks. It appears that, although for these examples the ages obtained by incremental heating of irradiated samples are higher than conventional K-Ar ages, this application of the Ar^{40}/Ar^{39} technique does not give the true age of the rocks.

Problems of sample inhomogeneity in K-Ar dating

Continuing studies by C. O. Ingamells and J. C. Engels have shown that errors in K-Ar dating are often due more to sample inhomogeneity than to analytical imprecision and that when contaminants are of a different age than the mineral being dated, a mathematical adjustment of the age is necessary. A $LiBO_2$ flux technique has also been developed to determine potassium and argon on the same split of sample, thus eliminating sampling errors.

The importance of sample inhomogeneity has often been overlooked. A literature survey of potassium contents of 2,700 biotites shows average values of: 7.99 percent K_2O in K-Ar dated samples, 8.57 percent K_2O in bulk chemically analyzed samples, and 9.29 percent K_2O in biotites analyzed by electron microprobe. Comparisons were also made of: (1) CaO and Na_2O in bulk chemical analyses versus microprobe analyses, (2) reported percentage impurity versus percentage K_2O, and (3) relative error in repetition determinations versus percentage K_2O. All the data indicate that biotites should generally contain between 8.0 and 9.5 percent K_2O, values below 8.0 percent K_2O being due to sample impurities. Further impurity levels are difficult to determine and are often underestimated or not reported, even though they can be crucial to interpretation of K-Ar ages. Consideration of percentage K_2O and

[128] nvt, integrated neutron flux.

[129] Murphy, F. M., 1932, Geology of a part of the Panamint Range, Calif.: Mining in California, v. 28, nos. 3 and 4, p. 329–356.

relative error may help geologists to reevaluate published age data as well as to provide guidelines for those currently preparing geochronologic samples and standards.

Middle Eocene diatremes in north-central Montana

R. F. Marvin and R. E. Zartman have obtained K-Ar ages on phlogopites from six dikes related to diatremes in north-central Montana. These diatremes have been described by Hearn[130] as subsidence ring structures which were produced by gas-rich eruptions of alkalic ultramafic magmas. Inclusions derived from both far above and far below the present surface are found within these pipelike bodies, and the youngest stratigraphic unit–the middle Eocene volcanic rocks of the Bearpaw Mountains–provides a maximum age for the diatremes. Radiometric ages from five of the intrusions range from 47.1 to 50.7 m.y., which would place the time of crystallization in the middle Eocene. Because the deformation and volcanism in the Bearpaw Mountains postdate deposition of the Wasatch Formation (lower Eocene) and predate emplacement of the diatremes, these results suggest that tectonism in the area occurred very rapidly in the middle Eocene time. Phlogopite from the sixth dike was obviously xenocrystic, and the presence of excess radiogenic argon was evidenced by an impossibly old "age." It is not known whether this mica originally was cognate with the peridotite magma, or whether it represents accidental inclusions of basement rock through which the dike extends.

Fission-track dating of diatremes

C. W. Naeser has shown the fission-track technique to be very useful in dating diatremes and kimberlites. The time of intrusion of these unusual rocks can be found by dating the accessory minerals, especially apatite, present in crustal xenoliths in the diatremes. By use of this method, four diatremes–Mule Ear and Moses Rock in Utah, and Garnet Ridge and Buell Park in Arizona–were dated at approximately 31 m.y. Two kimberlites from Riley County, Kans., were dated at 115 m.y. and 123 m.y., with an uncertainty of about 10 percent.

Uranium-series dating, southern California

Uranium-series dating of fossil shells from six exposed marine terraces of southern California was completed by B. J. Szabo in cooperation with J. G. Vedder. Two of the samples (Newport Beach, 20 feet alt; Laguna Beach, 75 feet alt) yielded concordant Th^{230} and Pa^{231} dates of 69,000±10,000 yr. Several additional samples had to be dated using the open-system model and were found to be contemporaneous with the above two samples. These dates correlate well with published results dating the end of the last interglacial period: namely, 70,000±5,000 yr from deep-sea core dating, 76,000±5,000 yr from concordant dates on samples from the lowest coral-reef terrace at Barbados Island, and 86,000±9,000 yr based on open-system dating of shells from the first terrace at Palos Verdes Hills, Calif. A second group of samples appear to date an older terrace sequence in California (30- to 140-feet alt) with an average open-system date of 120,000±22,000 yr. The open-system date of one sample from Newport Beach (120 feet alt) of 190,000±40,000 yr correlated with the fourth or fifth coral-reef terraces at Barbados that were dated at 200,000±10,000 yr. Most samples from the higher terraces in southern California were found to be disturbed and not suitable for reliable dating. Samples of the 12th terrace at Palos Verdes Hills, Calif., however, indicated ages older than 360,000 yr, and the best estimate for this terrace is 500,000±150,000 yr.

Evaluation of the K-Ar isochron method

Using data from Antarctica and Nevada, R. W. Kistler has made an evaluation of the K-Ar isochron method as described by Hayatsu and Carmichael.[131] In the mafic Dufek intrusion of Antarctica individual mineral ages of 95 m.y. for pyroxene and 166 m.y., 168 m.y., and 170 m.y. for plagioclase were obtained. On an Ar^{40}/Ar^{36}–K^{40}/Ar^{36} plot, data for the pyroxene and plagioclases are colinear with a slope equivalent to an age of 167 m.y. and an extrapolated initial Ar^{40}/Ar^{36} value of 275.

In the Ruby Mountains, Nev., amphibole ages of 48 to 121 m.y. and mica ages of 20.5 to 36 m.y. were obtained. These data show a systematic relationship to klippen in the range, with the youngest ages being in strongly cataclastic rocks. On an Ar^{40}/Ar^{36}–K^{40}/Ar^{36} plot, the youngest ages remain the same on a 20.5-m.y. isochron with an initial Ar^{40}/Ar^{36} value of 296. The minerals away from the thrust fault, however, now yield muscovite-biotite and biotite-amphibole pair isochrons that are parallel to the 20.5-m.y. isochron but with initial Ar^{40}/Ar^{36} values as high as 650.

The K-Ar isochrons bring the K-Ar data into better agreement with the Rb-Sr mineral isochron from the same rocks. For example, specimens from the eastern part of the range yielded K-Ar ages of muscovites and biotites that were between 30 and 34 m.y., whereas a plagioclase–K-feldspar–biotite Rb-Sr isochron for these rocks is 23 m.y. In fact, the total Rb-Sr mineral data yielded an average of about 22 m.y. except for one muscovite from the east front of the range. Hayatsu and Carmichael have anticipated this case of parallel K-Ar isochrons in areas of very mild metamorphism.

This reassessment of the Ruby Mountain K-Ar data strengthens the case for a Miocene event in the range. However, the strontium and argon isotopic equilibration in minerals in rocks in the whole range and the thrust fault on the west side

[130] Hearn, B. C., Jr., 1968, Diatremes with kimberlite affinities in north-central Montana: Science, v. 159, p. 622–625

[131] Hayatsu, A., and Carmichael, C. M., 1970, K-Ar isochron method and initial argon ratios: Earth and Planetary Sci. Letters, v. 8, p. 71–76.

of the range are more likely effects of the same cause rather than the fault being the cause of the isotopic equilibration.

Age of Keweenawan Peninsula native copper mineralization

J. D. Obradovich, in cooperation with W. S. White and N. K. Huber, determined a Rb-Sr isochron age of 1,095±27 m.y. on authigenic adularia and microcline associated with native copper deposits in Michigan. This age indicates that mineralization was penecontemporaneous with the igneous activity for which a chronology can be constructed from a variety of sources dealing with the middle and upper Keweenawan of Michigan, Minnesota and Wisconsin. A chronology based on work of the Geological Survey and also on the published research of others follows:

1. Extrusion of the North Shore Volcanic Complex and Portage Lake Lava Series accompanied by the intrusion of the Duluth Gabbro Complex on the north shore and similar gabbros on the south shore at 1,115±15 m.y. ago.
2. Native copper mineralization at 1,095±27 m.y. ago.
3. Deposition of the Copper Harbor Conglomerate, Nonesuch Shale, and Freda Sandstone prior to 1,055±35 m.y. ago.
4. Copper mineralization within the Nonesuch Shale at 1,075±55 m.y. ago.

SEDIMENTOLOGY

Sedimentology, the study of sediments and sedimentary rock, in the U.S. Geological Survey is primarily directed toward two goals: (1) solution of water-resources problems, and (2) determination of the genesis of sediments and application of this knowledge to sedimentary rocks for more precise interpretation of their depositional environment. Many studies by the Geological Survey involving sedimentology are directly applied to other geologic disciplines, such as marine, economic, and engineering geology, and to regional stratigraphic and structural studies, and are described elsewhere in this volume under their appropriate headings. Studies of fluvial sedimentation are directed toward the solution of water-resources problems involving water-sediment mixtures.

TRANSPORT PROCESSES

Models for stationary Gaussian processes

C. F. Nordin, Jr., and D. R. Dawdy have found that records of ocean waves, sand waves, turbulence, and a variety of hydrologic phenomena can be represented approximately as continuous stationary Gaussian processes. The records can be modeled by a broken-line process for computer simulation that preserves properties of the crossings, distributions of the maxima, and characteristics of the Hurst range. The simulation model was verified by using records of turbulence, sand waves, and stream flow, which gave satisfactory agreement.

VARIABILITY OF SEDIMENT LOADS

Sediment data for streams in California

Average annual suspended-sediment yield to the Sacramento River by west-side tributaries has been calculated as about 3.4 million tons. Studies by B. L. Jones, N. L. Hawley, and J. R. Crippen showed that, on the average, another 1.3 million tons is eroded annually from basins upstream from reservoirs and lakes but is entrapped and retained in the lakes. Average annual sediment yield from the tributary basins ranged from less than 100 to more than 3,000 tons per sq mi.

Sediment yield in the region varied greatly from year to year and from one time to another during the year. In the wet year, 1965, more than 3.5 times the average annual quantity was carried past the sampling site on the North Fork of Cache Creek, but in the dry year, 1961, the quantity transported was less than 7 percent of the average. In most of the study area, about 90 percent of the sediment was transported in only 3 percent of the time.

J. M. Knott has found that the sediment yield of Colma Creek, a tributary to San Francisco Bay, is affected significantly by construction activities related to urbanization. Historically, as much as 20 percent of the basin has been under urban development at one time; this has increased the quantity of sediment deposits in stream channels, which must be dredged periodically. Total sediment and water discharge was monitored during six storm events in 1969 and 1970. Data were collected simultaneously during these storms at sites downstream from areas that were undeveloped and had vegetal cover, were urbanized or under construction, and at an established sediment station near the lower end of the Colma Creek basin. During large storm events, the urbanized basin produced about 5 to 8 times as much total sediment as that from the undeveloped basin. The basin undergoing construction produced from 40 to 80 times more sediment than the undeveloped basin in 1969, but only 10 times more in 1970 when a smaller area was under active development.

Preliminary studies by W. M. Brown III showed that the estimated suspended-sand discharge of the Russian River to its estuarial reach was 510,000 tons per yr. A need for more detailed sand-transport analyses was indicated because of the prevailing instability in the water-sediment relations resulting from recent flood effects on the system, the complexity of the regulated river system, an insufficiency of pertinent sand-transport data, and the unknowns of estuarial processes.

VARIABILITY OF SEDIMENT YIELDS

Urban sediment control

In a study of sediment yield of small urbanizing basins in the Washington, D.C., metropolitan area, W. J. Davis and T. H.

Yorke found that construction in an area is the dominant factor affecting the sediment yield of a basin. However, more important to the problem of sediment control is a variation among basins of the unit-area yields of construction sites. This variation has been found to be related to land slope on construction sites and proximity of the sites to defined stream channels. The strong influence of these two factors indicates that site selection and fitting of a development to existing topography (taking advantage of the potential for natural sediment control) are important economic aspects of urban sediment control.

Sediment loads contributed to Pyramid Lake valley, Nevada

The Truckee River originates high in the Sierra Nevada at Lake Tahoe, along the California-Nevada State line, and empties into Pyramid Lake, a closed-basin desert lake about 60 mi to the northeast. According to P. A. Glancy and A. S. Van Denburgh, streamflow at the farthest downstream gage, about 10 miles upstream from the lake and at the southern boundary of Pyramid Lake valley, totaled about 970,000 acre-ft for the year, with a 3-month period of sustained high flow that averaged about 3,500 cfs. (Average annual flow, on the basis of a 41-yr record, is approximately 245,000 acre-ft.) On the basis of reconnaissance sediment sampling, the sediment load of the Truckee River past the Nixon gaging station was estimated at about 650,000 tons for the 1969 water year. That load represents about 270 acre-ft of upstream eroded material. The maximum measured concentration of suspended sediment during the year was 2,400 mg/1 on January 20, 1969.

Sediment yields in Hawaii

A reconnaissance report, based on sediment data collected during the 1966–69 water years, indicates annual suspended-sediment yields of from 630 to 1,400 tons per sq mi for seven basins on the island of Oahu. Computed bedload yields are 75 to 900 tons per sq mi annually. Estimated sediment discharge to Kaneohe Bay, windward Oahu, is 25,000 tons per yr.

Rapid development of land for urban use on Oahu causes changes in both runoff and sediment yield. High precipitation, deeply weathered rocks, and steep slopes are factors in an unstable terrane, in which slight alterations can cause large increases in erosion rates.

Avalanches and channel erosion, Nelson County, Va.

H. P. Guy and G. P. Williams found that avalanches and channel erosion caused by a catastrophic rainstorm August 29, 1969, resulted in an average of 2 to 3 inches denudation for some basins in the mountainous areas of Nelson County, Va. In Polly Wright Cove, typical of many basins, the yield was at the rate of 2.9 and 2.1 million cu ft per sq mi from avalanches and channel erosion, respectively. Downstream from the mountainous area, deposition ranged from about 400 cu ft per ft of channel at the head of the cove to about 120 cu ft per ft of channel 4,000 feet downstream. Total deposition in the cove amounted to about 37 percent of the total sediment eroded. The average particle size was more than 15 mm at the head of the cove and 0.6 mm 4,000 feet downstream.

DEPOSITION

Sedimentary facies of Glenns Ferry Formation

H. E. Malde reports that correlation of the Glenns Ferry Formation along a 50-mile stretch of the Snake River between Hammett and Hagerman, Idaho, illustrates the interplay of sedimentary facies that existed concurrently in the Snake River Plain in Pliocene-Pleistocene time. Areas of flood-plain deposition mingled with lacustrine areas which, in turn, gave way to areas dominated by open channels. These contrasting environments are identified partly by distinctive lithologies and partly by the remains of fossil vertebrates, mollusks, and pollen. Their correlation is established by the use of numerous marker beds of volcanic origin, including identifiable layers of siliceous volcanic ash, which are interbedded in the lake and stream deposits. Deductions about the relations between the paleoenvironments thus depends on the dating technique known as volcanic ash chronology. Altogether, the mingling of sedimentary facies in this part of the Glenns Ferry Formation make a stratigraphic section about 2,000 feet thick.

By geologic mapping in an area of 1,000 sq mi along this reach of the Snake River, H. E. Malde and H. A. Powers[132] also have determined the geographic distribution of the various sedimentary facies of the Glenns Ferry Formation.

GLACIOLOGY

Research by glaciologists of the U.S. Geological Survey is directed toward the better understanding of snow, ice, and glaciers as water resources, as elements in the meteorologic and hydrologic environment of the high mountains, and as indicators of climatic change. This requires studies of the dynamics of ice flow, the relation of heat and mass exchanges at snow and ice surfaces, and the development and testing of new mass-balance measuring procedures.

Glacier-dammed lakes and outburst floods in Alaska

Glacier-dammed lakes and outburst floods in Alaska have been investigated by Austin Post and L. R. Mayo. These lakes form along glacier margins or where glaciers block ice-free side valleys and create dangerous floods when the ice dams fail.

[132]Malde, H. E., and Powers, H. A., 1971, Geologic map of the Glenns Ferry–Hagerman area, west-central Snake River Plain, Idaho: U.S. Geol. Survey Misc. Geol. Inv. Map I-696. [In press]

Approximately 750 glacier-dammed lakes and downstream flood-hazard areas have been mapped. Information about the history of 32 of the most important lakes was obtained; these data, together with recent outburst hydrographs, illustrate the variability of glacier-dammed lake releases and the spectacular nature of many of the resulting floods.

Folded medial moraines of Bering Glacier

The folded medial moraines of the Bering piedmont glacier in Alaska have been investigated by Austin Post. During surges of the glacier, culminating in 1960 and 1966, ice displacement of as much as 9 and 4 km, respectively, took place. Ice flow in the piedmont lobe, mapped in 1957, 1963, and 1967, followed a normal, radiating pattern which does not result in folding. The folded structures are believed to be formed by small lateral displacements of medial moraines which take place far up the valley when the main glacier periodically surges past steadily flowing tributary glaciers. These irregularities are later spread laterally and shortened radially into large folds where the ice spreads out in the piedmont lobe.

Comparison of mass-balance techniques

Standard glaciological and hydrological mass-balance determinations frequently give results differing as much as 10 to 15 percent. An attempt was made by R. M. Krimmel, M. F. Meier, and W. V. Tangborn to measure the mass change of South Cascade Glacier, Wash., by three different and nearly independent methods. Detailed surface-level surveys, made in spring and fall, were used to give a volume change which was then compared to both surface mass-balance data obtained by glaciological techniques and to water-balance (precipitation minus runoff) data obtained by hydrologic techniques for the same period of time. The liquid water storage in the glacier was found to change from spring to fall, and conventional streamflow measuring procedures appear to give values which are slightly high.

South Cascade Glacier time-lapse photography

Time-lapse photography, consisting of one frame per day for about 150 days, was made by R. M. Krimmel of the transient snowline in the South Cascade Glacier basin. The frame-by-frame photography was used to evaluate ice versus snowmelt, to determine the average albedo in the basin, and to provide a graphic picture of the changing snow cover during the ablation season.

International Hydrological Decade glacier hydrology

Snow, ice, and water-balance measurements were continued by L. R. Mayo on Gulkana and Wolverine Glaciers in Alaska during 1970, an unusual year for glacial growth. The size of Gulkana Glacier in the Alaska Range increased primarily as a result of abnormally cold summer temperatures, coupled with heavy summer snowstorms. However, total annual precipitation was near normal. The size of Wolverine Glacier near the Gulf of Alaska increased because of heavy and nearly continuous winter snowfall followed by cooler-than-normal temperatures during the melt season. The flows of both glaciers responded to the increase in mass. This is a marked contrast to conclusions of studies of South Cascade Glacier, Wash., by W. V. Tangborn and others; they found the mass balance to be the most negative recorded since 1958.

Rock glaciers

Surveys of two rock glaciers at 3,500 to 3,800 m altitude at lat 39°00′ N., in the eastern Elk Mountains of Colorado in 1964 and 1968 showed a downvalley movement of about 60 cm per yr over the 4-yr period, according to Bruce Bryant. Practically no disruption of their surfaces took place during the movement, and little change along surface profiles was detected. There appeared to be a lateral component of movement of both glaciers away from the highest valley wall.

Paleoclimatic results from Searles Valley

Searles Valley, in California, contained a sequence of large perennial bodies of water during pluvial episodes of late Quaternary time, and small saline lakes or salt flats during interpluvial episodes. The water that formed the large lakes came mostly from the east slopes of the Sierra Nevada, and correlations of glacial events in that mountain range with the pluvial events in Searles Valley appear reasonable. According to studies by G. I. Smith, fluvial episodes that are correlated with the late Wisconsin extended from about 24,000 to 10,500 yr ago. During this interval, the lake in Searles Valley had at least five expansion stages followed by four recessions and a final desiccation. Three of these expansions took place within the interval 14,000 to 10,500 yr B.P. The climates that controlled lake levels may have changed drastically within periods that averaged about five centuries. Some changes probably occurred during shorter periods. Such rapid fluctuations suggest that the climatic events were triggered, and that once started, change was rapid and inexorable.

PALEONTOLOGY

Research by paleontologists of the U.S. Geological Survey involves biostratigraphic, paleoecologic, taxonomic, and phylogenetic studies in a wide variety of plant and animal groups. The results of this research are applied to specific geologic problems related to the Geological Survey's program of geologic mapping, resource investigation, and to providing a biostratigraphic framework for synthesis of the geologic history of North America and the surrounding oceans. Some of the significant results of paleontological research attained during the past year, many of them as yet unpublished, are summarized in this section by major geologic age and area. Many additional paleontologic determinations are carried out by paleontologists of the Geological Survey in cooperation with Survey colleagues. The results of these investigations are reported under the section "Geological, Geophysical, and Mineral-Resource Studies," p. A16.

PALEOZOIC OF THE EASTERN STATES

Late Silurian—Early Devonian ostracode assemblages from Maine

Ostracode assemblages from the Eastport quadrangle, Washington County, Maine, studied by J. M. Berdan, appear to be useful in zoning the Hersey Red Shale Member of the Pembroke Formation and the Eastport Formation. The Hersey is characterized by a species of *Nodibeyrichia* associated with an undescribed species of kloedeniine ostracode. Apparently *Nodibeyrichia* does not range into the Eastport, but the lower part of the Eastport has two zones of kloedeniine ostracodes overlain by a barren zone where no ostracodes have as yet been found. The upper part of the Eastport above the barren zone contains several species of distinctive kloedeniine ostracodes which are different from those in the lower part of the formation. Kloedeniine ostracodes similar to those in the Hersey and lower Eastport have been found in red shale on the north end of Vinalhaven Island, Vinalhaven quadrangle, Knox County, Maine.

Silurian-Devonian rugose coral biogeography

A comparison of Late Silurian and Devonian rugose corals in eastern North America with those in Europe, by W. A. Oliver, Jr., indicates that latest Silurian corals in the Appalachians are assignable to Eurasian genera but that endemic (or native) species increase in percentage of total faunas toward the south. Early Devonian corals were of Eurasian genera in some facies but largely of endemic genera in others. By the end of the Early Devonian, rugose corals were mostly endemic on the generic level, and some endemic families are known. This condition persisted through Middle Devonian time during which some eastern North American genera reached Africa, and some Eurasian genera entered Michigan and Indiana, apparently from the northwest. The eastern isolation disappeared early in the Late Devonian, and coral faunas of this age are of cosmopolitan genera.

Early and Middle Devonian rugose corals in western North America are Eurasian types with relatively few genera in common with eastern North America. Faunas are so dissimilar that direct correlation by coral faunas between eastern and western North America is not practical at present.

The European part of this study was carried on under National Science Foundation Grant GB 8387 to George Washington University.

Devonian-Mississippian boundary

Studies of plant microfossils by J. M. Schopf from drill cores on Pine Mountain in eastern Kentucky disclosed relationships of dominant elements and conodont zones similar to those 200 mi away in Ohio. This is of further interest because very similar occurrences (the "*lepidophytus*" zone) have been reported in Britain, Belgium, and White Russia. It has been suggested that these relationships can be used to identify the Devonian-Mississippian contact.

Bryozoan zonation in the Ordovician of Kentucky

Lexington Limestone of central Kentucky is a major rock unit that consists of several intertonguing carbonate rock types with abundant and diverse fossil faunas. O. L. Karklins has studied the bryozoans from the different carbonate environments represented in the Lexington Limestone[133] and has divided the formation into two informal zones, A and B, in ascending order. These two zones are based on changes in the bryozoan assemblages and ranges of the species.[134] The boundary between zones A and B is considered also to be the boundary between the Middle and Upper Ordovician in central Kentucky. This zonal boundary crosses several lithic boundaries, and thus it is an especially useful time-rock marker. In the reference section of the Lexington Limestone this boundary is in the upper part of the Brannon Member. To the north of the reference section the boundary is in the top layers of the Grier Limestone Member (Franklin and Owen Counties) and to the southeast in the Sulphur Well Member (Jessamine and Madison Counties).

Pennsylvanian palynology of Kentucky

Palynologic investigations by R. M. Kosanke of seven coals and associated strata from the upper Breathitt and Conemaugh Formations of Pennsylvanian age from northeastern Kentucky have established the range zones of more than 30 genera of spores and pollen. The range zones of *Cristatisporites, Densosporites, Lycospora, Murospora, Foveolatisporites, Torispora,* and *Vestispora* terminate within this interval. The range zone of *Cadiospora* originates in this stratigraphic interval, whereas the entire range zones of *Parasporites, Schopfites,* and *Spackmanites* are confined to this interval.

[133] Karklins, O. L., 1970, Preliminary bryozoan zonation of the Lexington Limestone (Ordovician) of Kentucky: Geol. Soc. America, Abs. with Programs, v. 2, no. 3, p. 224.

[134] Cressman, E. R., and Karklins, O. L., 1970, Lithology and fauna of the Lexington Limestone (Ordovician) of central Kentucky, *in* Geol. Soc. America, Southeastern Sec., Lexington, Ky., 1970, Guidebook: Lexington, Ky., Kentucky Geol. Survey, p. 17–28, cross sections.

PALEOZOIC OF THE WESTERN STATES

"Precambrian" humbug

Peculiar white circular markings composed of ovate cells arranged in a crude spiral were found about 10 years ago by David Hawley (Hamilton College) in the Altyn and Siyeh[135] Limestones of Glacier National Park, Mont. These markings were interpreted by some geologists as Precambrian algae. Similar markings were found later by R. C. Gutschick (University of Notre Dame) in the Allan Mountain Limestone at a locality in the Sawtooth Mountains, Mont. Last summer more specimens were discovered by W. J. Sando in the Madison Limestone of the Beartooth Mountains, Mont., and the Wind River Mountains, Wyo. The Wyoming specimen includes an attached bees' nest with the same morphology as the original "algae" markings, clearly demonstrating the recent origin of these puzzling objects. Pupae found in the nest were identified by P. D. Hurd, Jr. (Smithsonian Institution) as the genus *Osmia*, a Holarctic bee that is now widespread in the Rocky Mountain region.

New Ordovician zonal interpretations in Nevada

Ordovician graptolites of the zone of *Paraglossograptus etheridgei* (late Llanvirn) are associated with brachiopods and trilobites correlated with the *Orthidiella* zone in the June Canyon sequence, Ikes Canyon, Toquima Range, Nev. This discovery was made by E. H. McKee and R. J. Ross, Jr., (USGS) and W. T. Dean (Geological Survey of Canada) in August 1970.

On the basis of evidence from western Utah, the *Orthidiella* zone has been considered as old or older than the zone of *Didymograptus bifidus* (early Llanvirn).

One must now conclude that (1) the impressively large fossil assemblage of brachiopods and trilobites of the *Orthidiella* zone lived through a longer time span in the muddier more westerly transitional facies represented in the June Canyon sequence, or (2) the relationship between the zones of *D. bifidus* and *P. etheridgei* needs reexamination and revision; the indices of the zone of *D. bifidus* are found in the carbonate-shelf environment, but are peculiarly absent in the black-shale facies from Nevada to Yukon Territory. It is possible, therefore, that the two zonal assemblages are contemporaries and each is limited to its own environment.

A new Late Cambrian trilobite faunule from Nevada

According to M. E. Taylor a Late Cambrian (late Franconian–early Trempealeauan) faunule from the Hales Limestone of the Hot Creek Range, Nye County, Nev., contains the trilobites *Charchaqia*, *Hedinaspis*, and *Westergardites*, which were previously unknown from North America outside of Alaska. Elements of the faunule are similar to occurrences reported from Australia, western China, and east-central Alaska.

The central Nevada occurrence of the *Charchaqia* faunule contrasts markedly with coeval assemblages from the eastern Great Basin which contain no non-agnostids in common. Coeval lithofacies also differ between central Nevada and the eastern Great Basin. Strata associated with the *Charchaqia* faunule are typically thin bedded, rich in carbonaceous material, and penecontemporaneously slumped and brecciated. Coeval limestones in the eastern Great Basin contain algal stromatolites, thickly bedded calcilututa, and coarse-textured scour-and-fill structures.

The apparent lithofacies restriction and the wide geographic distribution of the *Charchaqia* faunule suggest that it may contain species adapted to life in deep water (off-shelf) and (or) open ocean habitats.

Devonian coral of the Great Basin

C. W. Merriam has completed a report on Middle Devonian rugose corals from the Great Basin in which 20 genera and subgenera or rugose corals are described from coral zones F and G. The entire Devonian of this province includes the nine coral zones, A to I, in ascending order.

This study of Middle Devonian rugose coral distribution points up the existence of belts of differing lithologic and faunal facies in the central Great Basin. Zone F coral faunas are best represented in the Antelope–Roberts Mountains north-south facies belt; those of coral zone G characterize the more easterly Diamond Mountains facies belt.

In coral zones F and G there are large solitary Rugosa of the families Digonophyllidae and Ptenophyllidae which are related to species of western Canada and the Rhine Valley of Germany. Among colonial genera the yardarm carinate *Hexagonaria* is common in zone F of the Antelope–Roberts Mountains belt and occurs abundantly in thrust outliers of the new Cockalorum Wash Formation wherein it built incipient patch reefs. Colonial *Sociophyllum*, *Utaratuia* and *Taimyrophyllum* of Great Basin coral zone F occur also in the correlative Hume and Nahanni Formations of Western Canada. Coral zone G at the bottom of the *Stringocephalus* zone is correlative with Rhine Valley Givetian; zone F below *Stringocephalus* is considered late Eifelian and correlative with the Junkerberg Schichten of Germany.

Ordovician stratigraphy of Nevada

The top 40 to 100 feet of the Antelope Valley Limestone in the Ranger Mountains and south of Aysees Peak, Nevada Test Site, are of the same age as the lower Copenhagen Formation in the Monitor Range 175 mi. to the northwest. Brachiopods

[135]Of former usage; now called Helena Dolomite.

and trilobites collected by R. J. Ross, Jr., and L. A. Wilson (USGS) and W. T. Dean (Geological Survey of Canada) in 1970 include *Rhipidomena?*, *Lonchodomas*, *Calyptsulax*, *Eorobergia*, *Cybeloides*, *Anataphrus*, *Isotelus?*, and an indeterminate bathyurid and harpid.

This confirmation of previous evidence (R. J. Ross, r0695, p. 43–44) virtually eliminates the possibility of an unconformity between the *Anomalorthis*-bearing beds of the Antelope Valley and the overlying Copenhagen and requires a facies change from the Monitor Range southeastward. The same change has been noted from the Monitor Range to the Egan Range (R. J. Ross, r0695, p. 42, 51, pl. 21).

Revision of paraparchitacean ostracodes

On the basis largely of growth stages of several genera in the Paraparchitidae that he found in the platy limestone member of the Alapah Limestone (Meramecian), I. G. Sohn[136] has revised the Paleozoic ostracode superfamily Paraparchitacea. Study of these assemblages has allowed recognition of several genera among the group of more than 100 species that had previously been referred to *Paraparchites* Ulrich and Bassler, 1906. If *Paraparchites* and related genera are oriented so that the plenate end is posterior, the following conclusions become evident: dimorphism is exhibited in the width of the posterior or width below the midheight; the presence or absence of dorsoposterior spines is constant within the ontogeny of species, and these spines are not related to eyes; adults in some taxa may be smaller than instars in other taxa in the family; and reversal of overlap and hingement is not a dependable taxonomic criterion. The presence of a well-developed inner lamella removes this group from the Palaeocopida as presently defined.

Stratigraphic distribution of echinoderm plates in the Ordovician of Nevada and California

Two echinoderm assemblages, based primarily on disarticulated silicified plates recovered from acid residues, are present in the Antelope Valley Limestone of Nevada and eastern California, according to J. T. Sprinkle. These faunas characteristically occur in the *Orthidiella* and *Anomalorthis* zones of the Antelope Valley, and show a similar distribution pattern to most of the other "shelly fossils." Several types of echinoderm plates are especially distinctive, widespread, and abundant enough to be used as guide fossils to parts of the Antelope Valley. The discovery of complete and well-preserved echinoderms at Ikes Canyon in central Nevada has especially aided in the identification of many of the elements in the lower fauna.

[136]Sohn, I. G., 1971, New Late Mississippian ostracode genera and species from northern Alaska: U.S. Geol. Survey Prof. Paper 711-A. [In press]

Pennsylvanian carbonate rocks, Brooks Range, Alaska

The shallow-water open-marine carbonate rocks of the Wahoo Limestone on the north flank of the eastern Brooks Range are some 250 to 310 feet thick. These carbonate rocks overly, without an apparent hiatus, restricted marine to intertidal dolomitic carbonate rocks of the Alapah Limestone of latest Mississippian age. The carbonate rocks of Morrow age are predominately echinoderm-bryozoan wackestones and packstones, with minor amounts of ooid grainstones and lime mudstones. The carbonate rocks of Atoka age are in part crossbedded bryozoan-echinoderm grainstones with associated minor amounts of thin-bedded dolomites. Outcrop studies of the Wahoo Limestone in the Sadlerochit Mountains by A. K. Armstrong indicate that the Pennsylvanian beds from Morrow to Atoka age had a general progression from shallow-water open-marine sedimentation to higher energy shoaling water, oolitic sedimentation. The Wahoo Limestone is unconformably overlain by sandstones of the Sadlerochit Formation of earliest Late Permian age. The colonial coral fauna of the Wahoo Limestone is best developed in beds which are interpreted as deposited between oolitic tidal bars.

New evidence on position of Devonian-Mississippian boundary

A study by C. A. Sandberg, R. A. Scott, and Maurice Streel,[137] comparing Devonian and Carboniferous conodont spore assemblages in Montana, Utah, and the upper Mississippi Valley with those in Europe, sheds new light on the position of the Devonian-Mississippian boundary in North America. All the latest Devonian spore assemblages contain the worldwide index species *Hymenozonotriletes lepidophytus*, but latest Devonian conodont assemblages in Montana and Utah are dominated by a new primitive species of *Siphonodella* that is ancestral to the basal Mississippian index species *S. sulcata*. The lowest occurrence of true *S. sulcata* in the upper Mississippi Valley is in beds, informally called "Glen Park" Formation, which intervene between the Louisiana Limestone below and the Hannibal Shale above. Thus, the Devonian-Mississippian boundary is at the top of the Louisiana Limestone and not, as stated by other recent conodont studies, within the lower part of the Hannibal Shale.

Permian Tethyan fusulinids identified from Alaska

R. C. Douglass reports that Neoschwagerinid fusulinids have been recognized in Alaska for the first time. A collection sent in by S. H. B. Clark (USGS) from a locality about 17 mi east of Anchorage contains the genus *Cancellina* associated with some schwagerinids. *Cancellina* is known from several Tethyan

[137]Sandberg, C. A., Scott, R. A., and Streel, Maurice, 1971, Comparison between spore and conodont assemblages at the Devonian-Carboniferous boundary in Montana (western United States) and Europe: 7th Internat. Carboniferous Congress, Krefeld, Germany, Compte rendu. [In press]

areas including Yugoslavia, Afghanistan, China, and Japan. In North America it has been found in eastern Oregon and western Washington. The occurrence of *Cancellina* is not only the first evidence of Permian Tethyan fusulinids in Alaska but also represents the northernmost occurrence of Tethyan fusulinids known thus far.

MESOZOIC OF THE UNITED STATES

A Cenomanian Age for the Sciponoceras gracile zone

Ammonites identified by W. A. Cobban[138] from the basal bed of the Bridge Creek Limestone Member of the Greenhorn Limestone on the Model dome northeast of Trinidad, Colo., include *Calycoceras naviculare* (Mantell) and *Anisoceras plicatile* (J. Sowerby), species described originally from the Lower Chalk of England. Both species have been recorded from many localities in Europe and Africa in strata of Cenomanian Age. *Anisoceras plicatile* has been recorded from all the Cenomanian, whereas *C. naviculare* has been known only from the upper part. The presence of these fossils in the *Sciponoceras gracile* zone of the western interior sequence suggests that this zone should be assigned to the top of the Cenomanian rather than to the base of the Turonian as it has been commonly treated previously.

Judith River Formation pollen from Montana

Two new fossil pollen genera and species, *Siberiapollis montanensis* and *Montanapollis endannulatus*, were found by B. D. Tschudy in samples from the Judith River Formation type section in Montana. In the Rocky Mountain area, as far as is known, these two species are limited to upper Campanian rocks. These taxa are probably relatives of several species previously described from Upper Cretaceous sedimentary rocks from the Western Siberian Lowlands of the U.S.S.R. and of a species from the Maestrichtian of Canada.

CENOZOIC OF THE UNITED STATES

New Oligocene vertebrate find in South Carolina

Real estate development near Summerville, northwest of Charleston, S.C., involving clearing of land and digging of drainage ditches, has exposed Tertiary strata that had previously been inaccessible to study. Marine-mammal bones were found in the ditches by amateur collectors; this led A. E. Sanders (Charleston Museum) to initiate an excavation program in which he was joined by F. C. Whitmore, Jr. (USGS). The fossil-bearing beds consist of clay and sand and total about 4 feet in thickness. They unconformably overlie the Cooper Marl of Oligocene age. The fauna includes representatives of two primitive odontoceta (toothed whale) families, the Agorophiidae and Squalodontidae. The Agorophiidae are not known above the Oligocene, and the squalodonts at the site have skull structure more primitive than that of members of the family from the Miocene of the Chesepeake Bay area and more nearly comparable to forms from the Oligocene of Europe. Ruth Todd (written commun., August 27, 1970) has identified an assemblage of Foraminifera of early Oligocene age from near the base of the 4-foot vertebrate-bearing sequence. Also collected were sea turtles, shark teeth, bony fish remains, pelecypod molds and casts, gastropods, corals, and many hickory nuts and acorns.

Paleoclimatic interpretations of the Yorktown Formation

Of the 230 species of Ostracoda found by J. E. Hazel in the Yorktown Formation (upper Miocene–lower Pliocene) of Virginia and North Carolina, 59 are still living on the Atlantic Continental Shelf. As a result of studies of Holocene species the thermal tolerances of these forms are well known. These data are used to infer the marine climate represented during deposition of the Yorktown. During most of Yorktown time the climate was warm temperate, a climatic zone that today does not exist along the Atlantic coast because of the interaction of cold and warm currents in the Cape Hatteras area. During the last stage of Yorktown deposition, the marine climate was subtropical. During Yorktown time the marine climate was much more equable than at present.

Volcanism and the origin of "Horizon A"

Widespread sedimentary deposits throughout the western North Atlantic basin and the Atlantic coastal margin of the United States were found by T. G. Gibson (r1560) and K. M. Towe to contain mineral suites indicative of altered pyroclastic material. The suite includes opal-cristobalite, montmorillonite, and the zeolite clinoptilolite, in addition to ash and bentonite. The deposits are characteristic of a narrow time interval around latest early Eocene–earliest middle Eocene time and are interpreted as the result of a series of volcanic events during this time interval. The cherts making up the oceanic reflecting "Horizon A" are similar in age and are considered to have the same origin. The similar time interval was established on the basis of planktonic Foraminifera and nannoplankton.

The chert beds are derived not only from the silica in the volcanic ash during diagenesis but from the increased amount of silica and, importantly, phosphorus found in the water from solution of the ash during the geologic time involved. The average phosphorus composition of volcanic rock types ranges from 0.10 percent to 0.45 percent P_2O_5. The presence of large additional quantities of silica and phosphorus would increase

[138] Cobban, W. A., 1971, New and little-known ammonites from the Upper Cretaceous (Cenomanian and Turonian) of the western interior of the United States: U.S. Geol. Survey Prof. Paper 699. [In press]

the productivity of siliceous plankton, and their increased concentrations on the bottom plus the ash itself form the chert beds. Dissolution of the dead tests is inhibited by the increased silica abundance in the water.

Miocene vertebrates from Colorado

Several years of exploration of the Troublesome Formation in the valley of Piney Creek, Rickstrew Ranch area, Colorado, has yielded a small collection of fossil vertebrates. Research by G. E. Lewis on this collection shows that the rocks in this area can be correlated with the upper Miocene rocks of the upper part of the Troublesome Formation in Middle Park, Colo., and with the Sheep Creek Formation of western Nebraska, and that one giant wolf-family carnivore of the fauna is indistinguishable from *Amphicvon major* of the Helvetian of France.

Miocene pollen and spore assemblages from Prudhoe Bay, Alaska

A subsurface section some 2,000 feet in thickness from Prudhoe Bay, north slope of Alaska, is determined by E. B. Leopold from palynological evidence to be mainly of Miocene age. Samples from a well site located between the mouths of the Putuligayuk and Sagavanirtok Rivers yield rich pollen and spore assemblages from depths below 500 feet; pollen from the lower part of this section give evidence of a spruce-pine forest with hemlock, suggesting a growing season (average July) temperature of at least as warm as 12°C, some 6°C warmer than present. Above this lies a pollen zone characterized by a rich spruce-pine-hemlock and fir forest with hardwoods including members of Juglandaceae. This zone suggests an average growing season temperature of at least 18°C, some 12°C warmer than present at Prudhoe Bay. Above this zone and including the uppermost 500 feet of section is a zone with an impoverished flora much like the modern one, along with some reworked pollen grains of Late Cretaceous age. This upper zone may be of Quaternary age. Floras from the lower two pollen zones appear to be of early and middle Miocene age, respectively, based on their resemblance to floras of that age from Cook Inlet and the Alaskan Range. As in the more southerly Alaskan Miocene floras, they record a part of a climatic oscillation involving a cool early Miocene and a warmer middle Miocene climate. These Prudhoe assemblages lack the characteristics of dated Oligocene or earlier Tertiary floras from southern Alaska.

The significance of these findings relates to the fact that this is the most northerly outpost (lat 70° N.) for mixed conifer-hardwood forests yet found in North America, but they are similar to Miocene floras from northern Siberia at the same latitude.

Discovery of marine Paleocene rocks in Alaska

Recent collections of marine mollusks of Paleocene age from the Kulthieth Formation in southern Alaska made by George Plafker and identified by W. O. Addicott (p. B48–B52) indicated that Paleocene seas covered a much broader area along the North Pacific rim than was previously known. Prior to this discovery, marine rocks of Paleocene age were not known to occur any farther north than California near lat 40° N. The new occurrence in the Saint Elias Range near lat 60° N. further suggests that marine strata of Paleocene age may be more widely distributed in the Paleogene sequence of the Gulf of Alaska margin than has hitherto been suspected.

A preliminary revaluation of the late Miocene of California

Continuing studies by R. L. Pierce of benthonic foraminifers and fish scales from upper Miocene sections of California have revealed that: (1) The type Delmontian Stage of Kleinpell correlates with the "middle" and early Mohnian. (2) The *Bolivina obliqua* concurrent range zone makes up the lower part of Kleinpell's[139] Delmontian Stage. In and near the type area of this zone, foraminiferal species occur that Kleinpell considered stratigraphically restricted to below the Delmontian. (3) The fauna reported by Kleinpell[139] in the Reef Ridge Shale in Big Tar Canyon of the southern Diablo Range, some 140 feet below the Jacalitos Formation–Reef Ridge Shale contact, correlates Mohnian and not the superjacent Delmontian. Because this latter fauna reported by Kleinpell from the middle part of the Reef Ridge Shale does not represent the youngest Mohnian, the upper part of the Reef Ridge Shale probably is also of Mohnian age. (4) If range zones established in the San Joaquin basin for both benthonic Foraminifera and fish scales are used, most if not all of the Belridge Diatomite Member of the Monterey Shale in Chico Martinez Creek of the Temblor Range correlates with the Mohnian and not the Delmontian and lower Pliocene. (5) Both the type Delmontian and the type *Bolivina obliqua* concurrent range zones of Kleinpell correlate with his faunal definition of his Mohnian; all his concurrent range zones of the Mohnian and Delmontian Stages are in need of revision and redefinition; therefore, four concurrent range zones are being proposed for the Mohnian Stage of California.

Paleogene climatic fluctuations in western North Ameria

Analysis of Tertiary plant assemblages from western North America by J. A. Wolfe (r1680) indicates the occurrence of pronounced climatic fluctuations during the Paleogene. A late Eocene cool period about 40 m.y. ago is one of the most marked episodes. This was preceded by an extremely warm interval that saw the expansion of tropical rain forests north to about lat. 48° N. Other cool intervals include the early middle Eocene and the earliest Eocene.

[139] Woodring, W. P., Stewart, Ralph, and Richards, R. W., 1940, Geology of the Kettleman Hills oil field, California: U.S. Geol. Survey Prof. Paper 195, p. 121–122.

OTHER PALEONTOLOGICAL STUDIES

Functional morphology of the productid brachiopod lophophore

The largest internal organ in brachiopods, the one that largely determines the general shape of the shell, is the lophophore which creates the currents by which the brachiopod feeds and channels the food to the mouth. The shape and course of the lophophore of the suborder Productidina, one of the largest and most important groups of late Paleozoic brachiopods, has remained unknown because it was fleshy or spicular and hence not preserved. Three genera of small productidines now have been discovered in samples collected by R. E. Grant[140] from the Permian of Greece, in which the supporting tissue of the lophophore was calcareous and became silicified along with the shell, revealing an entirely ptycholophous form. Previous reconstructions based on conjecture visualized the productidine lophophore as spiral. Knowledge of the actual shape of this organ allows interpretation of the feeding habits, orientation, and ecological requirements of these important brachiopods. This insight also allows more accurate interpretation of their phylogenetic relationships, suggesting that the leptodids are closely related to the productids, and that the Thecideacea, important in Mesozoic faunas and still thriving in modern seas, are descended from the Paleozoic Productidina and live in much the same way. All these factors are important in attempts at correlation and paleoecologic interpretation of the late Paleozoic that depend upon the distribution of productids.

Origin of the Cephalopoda

Specimens of Late Cambrian mollusks collected from the Ellsworth Mountains, Antarctica, provide the basis for a new hypothesis regarding the origin of the cephalopods. E. L. Yochelson suggests that a radiation of the Monoplacophora during the Late Cambrian provided a variety of shell forms derived from a simple cap-shaped shell. In one lineage, increase in height of the shell caused anterior-posterior compression of the soft parts. This in turn led to development of septa to keep the soft parts closer to the aperture. The Antarctic Cambrian specimens are high curved cones containing a multiple number of septa. The presence of a siphuncle piercing the septa is the only basic difference between the septate conical Cambrian specimens and the earliest known cephalopod.

Computer assistance in the study of fusulinids

The discrimination and description of species in the fusulinids depend in part on the interpretation of numerical data derived from measurements made on a number of attributes at various stages of growth. Computer programs have been developed by R. C. Douglass and N. J. Cotner to take the raw measurement data and from it compute several useful statistics at equivalent diameters. Growth curves can be machine plotted, showing the change in attributes with increase in specimen diameter. These curves allow for comparison between specimens or groups of specimens over their entire growth period. They provide more useful and reliable comparisons than had been available previously and will, therefore, allow for more certain identifications of the fusulinids and better correlation of the stratigraphic units.

Ordovician brachiopods from Norway

Early Ordovician brachiopods and trilobites and Late Ordovician brachiopods not previously reported from the Norwegian Caledonides were collected from the Hølanda area, about 35 km southwest of Trondheim, by R. B. Neuman (USGS) and D. L. Bruton (Paleontological Museum, University of Oslo). The fossils were found in tuffaceous rocks at five localities, one of Arenigian Age and four of Ashgillian Age. The Arenigian assemblage consists of six genera of brachiopods being studied by Neuman and a similar number of trilobite genera under Bruton's study. Four of the brachiopods are hitherto undescribed strophomenides, one is a new clitambinitid, and one is an orthid. The assemblage is like North American assemblages of this age in its apparent endemic character. The Ashgillian-Age brachiopods are genera that occur in similar equivalent rocks in the northern Appalachians and elsewhere.

Early Devonian rugose corals of Czechoslovakia

W. A. Oliver, Jr. (USGS), and Arnošt Galle (Czechoslovakian Geological Survey) have completed a study of the Early Devonian rugose corals of the Upper Koneprusy Limestone in central Bohemia, Czechoslovakia. In addition to the redescription of a key fauna, the study involved the interpretation of evolutionary relationships with Silurian and later Devonian corals based primarily on the microstructure of septa and walls. Some apparent lineages can be traced from the Gotland fauna (Silurian, Sweden) to the Koneprusy and contemporary Australian faunas, and into widespread Middle Devonian faunas. Similar eastern North American Early Devonian corals are completely different in detailed morphology and appear to represent parallel or convergent evolution in similar (reef) environments. The work was done in the laboratories of the Czechoslovakian Geological Survey, Prague, while Oliver was on a 6-month National Academy of Sciences–Czechoslovak Academy of Sciences exchange visit.

Ancestry of monachine seals

In cooperation with the South African Museum, Cape Town, Q. B. Hendey (South African Museum) and C. A. Repenning

[140]Grant, R. E., 1971, The lophophore and feeding mechanism of the Productidina (Brachiopoda): Jour. Paleontology. [In press]

(USGS) have completed a study of a Pliocene seal from South Africa which provides the first fossil evidence of the ancestry and antiquity of the living Antarctic monachine seals. This fossil is intermediate between the living crabeater, leopard, Weddell, and Ross seals and fossil forms of the Mediterranean area and demonstrates a number of evolutionary patterns which help to interpret the relationship of previously known fossil phocids from both the European area and eastern United States. As a result the fossil phocid seals can be evaluated in terms of known adaptational patterns for the first time; prior to this most significant discovery, they could only be compared to living seals with no firm concept of evolutionary patterns.

Underwater hearing in seals

Prompted by unexplained differences in fossil seal skull structures, C. A. Repenning has completed an interpretation of the functional anatomy of seal ears which indicates a complex evolutionary adaptation to perfect hearing of waterborne sound and to protect these delicate structures from the great pressure of underwater life. The different seal families have followed different patterns of evolution to accomplish these adaptations, and recognition of these several patterns greatly aids in identification of familial relationships of fossil seals as well as suggests the nature of the ear of the ancestor of seals.

GEOMORPHOLOGY

Pre-Wisconsin glaciations in southeast Indiana

L. L. Ray reports that large areas in southeast Indiana are mantled by glacial drifts of Nebraskan and Kansan rather than Illinoian age, as previously thought. The Nebraskan, the most widespread glaciation, crossed the site of the present Ohio River, where it borders southeast Indiana, as far downstream as the vicinity of Louisville, Ky. The second glaciation, the Kansan, was somewhat less extensive and did not reach at all points as far as the present Ohio River valley. Erosion following the Kansan Glaciation produced a deeply dissected topography that strongly influenced the advance of the third, or Illinoian, ice sheet, channeling a narrow, sinuous ice tongue down the lower Great Miami and Ohio River valleys to a point near the confluence with the Kentucky River. Remnants of moderately weathered Illinoian Drift within the Ohio River valley contrast sharply with the deeply weathered tills of Nebraskan and Kansan ages on the adjacent dissected uplands of Indiana and Kentucky.

Erosional history, Black Canyon of the Gunnison River, Colo.

W. R. Hansen reports that profile breaks in interravine ridges of the Black Canyon indicate that two distinct rejuvenations of canyon cutting occurred when the river was flowing at 1,500 to 1,600 feet and later at 800 feet above the present drainage. The later rejuvenation may indicate increased runoff in Pleistocene time or an episode of renewed uplift. Structural configuration of volcanic rocks indicates post-Oligocene regional warping and regional tilting to the east that may have continued into late Pleistocene time.

Streamflow data in the Gunnison River region show that average discharge as well as drainage area are inversely proportional to channel gradient. These relations can be used to approximate discharges of tributary streams that formerly entered the Gunnison River but that have been beheaded by drainage adjustments in late Cenozoic time.

Scour and fill in Tujunga Wash, Calif.

A unique combination of substantial channel change and documentation of the changes by high-order photogrammetry in Tujunga Wash in southern California was studied by K. M. Scott. Extensive scour and fill occurred during the 1969 floods in this 3-mi-long, partly urbanized fanhead valley. Maxima of about 20 feet of net scour and 35 feet of net fill were measured on cross sections representing 31,000 feet, which were plotted to illustrate changes in distributary channels of the wash. In the channel thalweg, net elevation change varied from as much as 14 feet of scour to as much as 16 feet of fill.

The most dramatic causes and effects of scour and fill in Tujunga Wash were: (1) the unexpected diversion of floodflow to a major distributary channel of the wash in an area where urbanization had progressed, (2) local reduction in base level which occurred when floodflow in both of the main distributary channels entered a large gravel pit, and (3) lateral scour of the main aggradational surface of the wash, partly attributable to natural adjustment of a distributary channel to flood discharge. An entire residential street, seven homes built on an unstabilized cutbank of the channel, and three bridges were destroyed as a result of these combined factors.

Additional scour and fill were due to the natural lateral shift of channels in broad, ephemeral washes and to locally raised base level.

Erosion by debris avalanches

Watersheds near Glendora, Calif., yielded catastrophic volumes of debris slurry during the recordbreaking 1969 storms. According to K. M. Scott (p. C242–C247), erosion rates sufficient to reduce the entire land surface by more than 2 inches occurred in several of a series of steep, mountain-front basins which had suffered brush fires in 1968. The most concentrated damage from debris flows occurred among homes built directly at the mouth of a basin with a drainage area of 0.09 sq mi and a relief of 1,400 feet.

Triggered in part by surficial slope failures, the debris flows mobilized channel-bed material and scoured channels to bedrock. This mechanism is probably the most common means of coarse-sediment transport in these and similar basins.

Channel oaks were of considerable value in retaining debris and reducing the number and size of hillslope failures of the type which triggered the flows.

In Virginia the debris avalanches that occurred in association with the 1969 floods usually took place along preexisting hollows or depressions on the hillside and were most common on hillsides facing north, northeast and east. Their magnitude and estimated frequency indicated to G. P. Williams and H. P. Guy that these debris avalanches are probably a very important erosional process on mountain hillsides in the eastern United States.

Recent epicycles of erosion and deposition

According to Deric O'Bryan, data related to the study of the Holocene epicycles of erosion and deposition in the lower San Juan drainage in the Southwest engendered some disconcerting questions when applied regionally to the theory expanded on by Hack[141] that erosion accelerated during dry periods and deposition prevailed in relatively moist series of years. Furthermore, according to Fritts and others,[142] the theory has been amplified to include temperature as well as precipitation; thus, warm, dry conditions are conducive to erosion, and cool, wet conditions to alluviation, and "the unexplained variability in these climatic relationships amounts to only 9 to 13 percent".

Tree-ring chronologies have been compiled for many sections of the Southwest; these records span almost 2,000 yr in southwestern Colorado. Agreement is general that a narrow annual ring marks a dry year. Deric O'Bryan's studies of relationships between yearly (but not seasonal) precipitation and temperature, tree ring width, and annual crop yields, demonstrate close relationships in spite of marked but consistent areal differences in precipitation and temperature.

Records of climate from three weather stations—Northdale, Cortez, and Mesa Verde National Park headquarters—in the southwestern corner of Colorado are available from the 1920's to date. Altitudes range from 6,177 feet at Cortez and 6,482 feet at Northdale, to 7,070 feet at Mesa Verde. Pinyon, growing in close proximity to each of the three stations, provide tree-ring width values. Harvest yields of nonirrigated corn and beans have been compiled by the U.S. Department of Agriculture since 1929 for the area where they are grown between Cortez and Northdale. The interval between 1929 and 1960 has been selected as the period of study because corn became a negligible nonirrigated crop after 1960 (C. N. Guellow, U.S. Dept. of Agriculture, Statistical Reporting Service, written commun., 1969).

Mesa Verde is high, warm (mean annual temperature is 50.4°F.), and comparatively wet (mean annual precipitation is 18.14 in.). Cortez is relatively low, intermediate in temperature (48.8°F.), and dry (13.14 in.). Northdale is intermediate in altitude, cool (44.9°F.), and dry (13.41 in.). A dry year at Mesa Verde (14.00 in., rank 29 of 32) would be fairly wet at Cortez (rank 9 of 32) and above average at Northdale (rank 13). Yet the tree rings show comparable patterns and equivalent actual widths. Temperature comparisons show similar, although less marked, variations.

Post-1880 erosion by arroyo cutting occurred on Mesa Verde, throughout the drier Cortez-Northdale area, and extensively in the Four-Corners region (Colorado-Utah-Arizona-New Mexico) of the Southwest. The variable local expectancy values for mean annual precipitation and temperature raise doubts about the veracity of generalizations such as "moist conditions are conducive to alluviation," and "erosion occurs in dry periods." There would appear to be other important related conditioning factors.

[141]Hack, J. T., 1942, The changing physical environment of the Hopi Indians of Arizona: Reports of the Awatovi Exped., Peabody Museum, Harvard Univ., Report 1, p. 39–80.

[142]Fritts, H. C., Smith, D. G., and Stokes, M. A., 1965, The biological model for palaeoclimatic interpretation of Mesa Verde tree-ring series: Am. Antiquity, v. 31, no. 2, pt. 2, p. 101–121.

Geomorphic processes studied in California

J. R. Beck and J. R. Ritter have used time-lapse photography to record the effect of wave action and littoral and tidal currents on erosion and building of a spit and sand bars at the entrance of Bolinas Lagoon about 15 mi northwest of San Francisco, Calif. These processes are clearly portrayed in a film that is being prepared for release along with a text that will describe the equipment used.

Investigations of geologic structure and composition, erosion processes, and land use indicate that the Newell and Zayante basins, Santa Cruz County, are subject to severe erosion as protective vegetation is removed from steep slopes and dip slopes. The processes attendant to excessive sedimentation in downstream reservoirs in these basins are being studied by W. M. Brown III.

GROUND-WATER HYDROLOGY

Research in ground-water hydrology is directed toward developing a better understanding of ground-water systems in order to furnish the management and planning tools needed for meeting the increasing demands imposed upon these systems. Listed below are selected examples of current research in ground-water investigations.

Artificial recharge

Florida.—According to W. C. Sinclair, flow-net analysis of the water-table aquifer in Hillsborough, Pasco, and Pinellas Counties, Fla., suggests that leakage from the water table to the Floridan aquifer is on the order of 0.5 mgd within the 1-sq-mi area most seriously affected by pumpage. This is about 3 percent of the total pumpage. Flow-duration analyses of nearby streams indicate that diversion of local runoff would be sufficient to maintain lake levels throughout the area of decline during periods of normal and excessive precipitation. This could be augmented by pumpage into the more important lakes from the Floridan aquifer during periods of deficient rainfall. The result would be maintenance of lake levels with leakage to the Floridan aquifer somewhat in excess of pumpage diverted to the lakes. Carefully monitored infiltration tests were conducted in a "typical" cypress-swamp sinkhole which had been dewatered by local pumpage. An average of 110,000 gpd was required to maintain the stage about 20 feet above the potentiometric surface in the Floridan aquifer to counter evapotranspiration (negligible) and infiltration to the water-table and the Floridan aquifers (about 3 gpd per sq ft). Infiltration tests of the major soil types in the area are in progress. Test ponds with vegetation typical of the area will be flooded in simulation of varying amounts of rainfall while the effects are monitored in deep and shallow observation wells; and changes in soil moisture, from land surface to water table, are measured by neutron probe. These tests, begun during the dormant season, will be repeated in summer in an attempt to differentiate evapotranspiration from infiltration.

F. A. Watkins, Jr., reported that the installation of a pilot well, connecting an unconfined sand aquifer to the confined Floridian aquifer, has been completed in the southwestern part of Orange County, Fla. Preliminary evaluation of the data from the test well indicates that it is functioning as predicted and is transferring water from the sand aquifer to the Floridan aquifer at a rate of approximately 10 gpm or 16 acre-ft per yr.

A large-scale artificial recharge test was conducted in a municipal well field at Jacksonville, Fla., by G. W. Love to determine (1) if artesian heads could be raised during periods of seasonally low water levels to pump water more efficiently, and (2) if it is feasible to store higher quality water in the aquifer than is presently there. Results of the tests indicated that artesian heads could be raised but could not be maintained at higher levels for a sufficient period of time to efficiently pump water; however, higher quality water from other areas could be efficiently stored in the aquifer in the vicinity of the well field.

Virginia.—Preliminary results of aquifer tests conducted by D. L. Brown at Norfolk, Va., on the brackish-water sand aquifer into which it is proposed to inject fresh water indicated that: (1) the specific capacity for the brackish-water aquifer, with varying rates of pumping, is 16.2 gpm per ft at 250 gpm, 15.1 gpm per ft at 500 gpm, 14.5 gpm per ft at 800 gpm, and 11.7 gpm per ft at 1,000 gpm; (2) the injected sand aquifer does not appear to behave like a leaky aquifer; (3) there is an image recharge boundary effect, occurring during the first 2 hours of pumping, that tends to increase the effective transmissivity and storage coefficient; (4) maximum head buildup during recharge is expected to be less than 30 feet if clogging is minimized; and (5) transmissivity varies from 40,000 to 60,000 sq ft per day in the well field because of changes in the aquifer thickness; the storage coefficient is 0.0002.

New York.—The rate of clogging of an injection well at Bay Park, N.Y., in which highly treated sewage-plant effluent is being recharged, is controlled primarily by the amount of solids suspended in the recharge water, according to a report by John Vecchioli (r0456) and H. F. H. Ku. Clogging is also attributed in part to bacterial growths in the aquifer around the injection well, and to deposition of iron and (or) aluminum phosphate compounds at the gravel pack—aquifer interface. Degasification of the injection water has not resulted in a measurable reduction of clogging. A simple descriptive model of microbial activity in the Bay Park recharge well to explain observed results and aid in the application of control measures has been developed by G. G. Ehrlich.

Minnesota.—H. O. Reeder made a study in West St. Paul, Minn., to determine the feasibility of recharging Cambrian and Ordovician aquifers by injecting water into the Prairie du Chien Dolomite, in which a large-diameter injection well was drilled. About 450 feet from the test well, small-diameter observation wells were drilled (in order of increasing depth) in St. Peter Sandstone, dolomite of the Prairie du Chien Group, and Jordan Sandstone. It was determined that the Prairie du Chien dolomite and the Jordan Sandstone are hydrologically connected to some extent; during pumping from the Prairie du Chien, reaction in the Jordan observation well lags 3 to 7 minutes behind the Prairie du Chien observation well. During a 48-hr test period, water was pumped at about 450 gpm and water levels declined 19 feet in the Prairie du Chien observation well and 12 feet in the Jordan observation well while the change in water level in the St. Peter observation well was negligible. The base of the St. Peter Sandstone apparently acts as a very effective aquitard.

Texas.—R. F. Brown, D. C. Signor, and W. W. Wood conducted artificial-recharge research investigations in the High Plains of Texas. Results indicated that low-permeability beds, which are present between the bottom of a spreading basin and the water table, limit artificial recharge by surface spreading. In order to determine the rate of vertical flow through the unsaturated zone, it is necessary to determine vertical permeability. Air-permeability measurements, made by measuring the rate of pressure change between the land surface and the water table resulting from a change in atmospheric pressure, were used to estimate vertical permeability. The method, described by Stallman and Weeks,[143] resulted in permeability measurements that were comparable to permeability measurements of core samples in the laboratory.

California.—J. A. Moreland evaluated 58 artificial recharge facilities, including injection wells, spreading grounds, and recharge basins in the upper Santa Ana Valley in California. A single-ring infiltrometer was used to determine potential infiltration rates at 22 sites. Grain-size analyses were made on surface soil samples and correlated with measured infiltration

[143]Stallman, R. W., and Weeks, E. P., 1969, The use of atmospherically induced gas-pressure fluctuations for computing hydraulic conductivity of the unsaturated zone [abs.]: Geol. Soc. America Abs. with Programs, pt. 7, p. 213.

rates. A direct relation of infiltration rate and grain size and an inverse relation of infiltration rate and sorting was observed. Correlation of infiltration rate and D_{20}/S_0 (20 percent-passing grain-size diameter divided by sorting coefficient) showed a log-log relation for samples from similar geologic environments. The study indicates that existing facilities are generally adequate to conserve local and mountain runoff. The most serious problem delineated was silt deposition in spreading grounds and basins which results in decreased recharge rates.

Oregon-Washington.—The use of injection wells as a means of artificially recharging basalt aquifers has been proven feasible, on the basis of experiments conducted in both Oregon and Washington by A. A. Garrett and C. J. Londquist. However, to reverse or slow the trend in water-level decline, resulting from intensive ground-water withdrawal in some parts of eastern Washington, as much as several thousand acre-ft of water annually would be needed for recharge. Such quantities are not available in many of the places where artificial recharge is most needed; studies to date suggest that Crab Creek is the only local stream whose flow is great enough to support an artificial recharge operation. A few of the centers of ground-water withdrawal are near enough to Crab Creek that water could be diverted from the creek and transported to them by means of pipelines and high-lift pumps. Large-scale diversion from major streams, such as the Snake River, is not economically feasible for recharge because many of the centers of ground-water withdrawal are so widely scattered that a vast network of distribution lines would be required.

General.—Jacob Rubin and C. D. Ripple developed several procedures for estimating the performance of ponds for ground-water recharge. These techniques are applicable to areas in which water flow is approximately steady and strongly influenced by a clogged, surficial soil layer. The procedures developed include experimental techniques for determining some of the most relevant sediment properties, and computational methods which make it possible to utilize the knowledge of such properties in order to estimate, for multilayered sediments, the expected relation between pond depth and recharge rate.

Hydrology of carbonate rocks

Studies of the Edwards Limestone aquifer in the Balcones fault zone of the San Antonio area, Texas, by R. W. Maclay and P. L. Rettmen, showed that regional movement of ground water can be determined by using natural tritium as a tracer. Interpretations based on 90 tritium analyses from samples taken from 30 wells distributed throughout the area agreed generally with interpretations of movement based on hydraulic head. A water-soluble dye, Rhodamine WT, is being used to determine the rate and direction of ground-water movement in local areas, and to determine the anisotropic character of the limestone aquifer. Preliminary results of these tests indicate that this field method should be developed further for determining hydraulic characteristics of complex limestone aquifers.

V. T. Stringfield (r2292) and H. E. LeGrand are studying the development and distribution of permeability in carbonate-rock aquifers and evaluating the water levels in them. A group of aquifers overlain by mature karst topography tends to have a permeability related to interconnecting large solution channels bounded laterally by dense relatively impermeable rock and bounded below by rock of decreasing openings. Another group, which may be considered paleoaquifers because they had solution channels developed under an earlier period of karstification, have been reactivated, and fresh water again circulates in them. Guidelines for reconstructing the geologic and hydrologic history of carbonate-rock terranes give many clues of the existing hydrologic conditions.

According to H. R. Anderson, large yields of fresh ground water (250–2,000 gpm) are obtained from a 1- to 2-mi-wide east-to-west band of Tertiary limestones through the San Juan, Puerto Rico, metropolitan area. Tertiary shales and sandstones below them yield significantly smaller quantities of water (0–250 gpm); and still older formations, lower Tertiary and Cretaceous tuffaceous sedimentary rocks, generally yield meager amounts of water. Ground-water flow in the San Juan area is from intake areas, such as Montes de Hatillo, northward to discharge areas of Laguna San José, Bahía de San Juan, and the Atlantic Ocean. Toward the Bayamón area, recharge is through the limestone ridges which form the topographic highs of the area, and flow is both into Bayamón drainage (north) and toward the Atlantic (north).

Model studies

Florida.—An electric analog model was used by C. A. Appel to estimate the water needed to maintain, during dry periods, specified "optimum" canal stages for existing and proposed canals in southern Dade County, Fla. On the basis of these studies, it was decided to consider the possibility of permitting levels to decline somewhat below the specified optimum levels for short periods to reduce the design water needs of the area.

Maryland.—Continuing investigations of the Magothy aquifer in the Annapolis area, Maryland, by F. K. Mack, showed that the aquifer has a much greater potential for development than was previously believed. A potentiometric map, prepared in 1970 and based on data from a new network of observation wells, shows that the potentiometric surface in the Magothy aquifer is as high as 80 to 100 feet above sea level in upland parts of the outcrop area, slopes gently toward the Severn River and Chesapeake Bay, and is at least a few feet above sea level except in a few small areas near active well fields. Need for revision of an earlier map of transmissivity distribution was shown by test drilling during 1969 and 1970. Preliminary trials were made with a refined electric analog model of the aquifer. The tests indicated that as much as 60 mgd may be available from the aquifer. Hazards of salt-water contamination have not been considered in this determination.

New York.—Preliminary tests of pumping concentrated in the middle of Long Island, N.Y., at rates approaching natural recharge resulted in maximum drawdowns of somewhat more than 100 feet in a two-layer resistor-capacitor model, according to O. L. Franke. Preliminary calibration of the steady-state north-south cross-sectional model was followed by several determinations of the approximate position of the salt-water—fresh-water interface as a function of varying recharge rates. Difficulties, as yet unresolved, arose in determining the position of the interface in a thick confining layer.

California.—A numerical digital-computer model, designed by Irwin Remson, was used by Chabot Kilburn to explore aquifer transmissivities and the water balance for the San Juan Valley, San Benito County, Calif. The model successfully generated the observed groundwater head distributions that occurred during November 1968. Ground-water recharge from all sources for the San Juan Valley during 1968 was about 11,200 acre-ft; ground-water discharge by pumping was about 11,000 acre-ft. A small part of the difference between inflow and outflow is attributed to unmeasured outflow from surface streams. The remainder, about 1.5 percent, is the result of minor errors. Kilburn is also exploring aquifer transmissivities and the water balance for that part of the Hollister ground-water basin that is east of the Calaveras fault zone in San Benito County, Calif.

A flood wave in an open channel may be modified by the movement of water through the streambed into a hydraulically connected aquifer. This phenomenon is difficult to study because of problems associated with field measurement and the development of physical models for laboratory investigations. G. F. Pinder used a mathematical model, in which numerical techniques are incorporated, to solve, simultaneously, the equations describing one-dimensional open-channel flow and two-dimensional areal ground-water flow. Darcy's law is used to determine flow through the streambed. Numerical experiments demonstrate that, when a permeable aquifer is hydraulically connected to a stream, a flood wave is considerably modified owing to bank-storage effects, particularly in the lower segments of a long reach.

A geohydrologic study of the Saugus-Newhall area of the upper Santa Clara River Valley, Calif., by S. G. Robson, involved the construction and verification of a two-layer electrical analog model of the basin. Various water-management proposals were explored, and the model indicated that the upper aquifer could not accept the quantities of imported water proposed for artificial recharge near Solemint. The artificial-recharge reach would have to be extended from Solemint to Bouquet Junction in order to recharge the imported water. The model further indicated that if ground-water demands increase at the maximum rate expected from 1970 to 1990, the area could experience a shortage of good-quality ground water in spite of the imported water. Both the geohydrologic study and the analog model indicate that the upper aquifer has limited ground-water storage potential and is markedly affected by the quantity of recharge to the aquifer from the intermittent streams in the area. The lower aquifer contains large quantities of ground water of questionable chemical quality in storage, and it is little affected by recharge from streamflow.

The overdraft on the ground-water supply of the upper Coachella Valley in California has been about 25,000 acre-ft per yr since 1945. An analog model was built to determine the effect of recharging as much as 60,000 acre-ft per yr. According to S. J. Tyley, results indicate that water levels in the area north of Palm Springs would rise more than 150 feet by 1990.

P. R. Wood has shown by an electric analog model analysis of the ground-water reservoir in the Santa Clara Valley, Santa Clara County, Calif., that the hydrologic system is much more complicated than was originally thought. The model studies have shown the need for more reliable information on: (1) rates of induced infiltration of water from streambeds; (2) volume of water added to the heavily pumped confined-aquifer system as a result of downward leakage from an overlying water-table aquifer; (3) vertical hydraulic conductivity of confining beds; (4) number, thickness, and vertical hydraulic conductivity of compressible beds that contribute water to the confined-aquifer system as a result of compaction caused by changes in stress created by pumping; and (5) change in aquifer storage with time. A digital computer is being used to study the operation of the hydrologic system.

A 2,400-node mathematical model of the Indian Wells Valley ground-water basin in California was developed and verified by R. M. Bloyd, Jr., and S. G. Robson. The alternating-direction implicit method was used to compute the mathematical solution. The assumption was made that there are only two aquifers in the valley, one deep and one shallow. The model for the deep aquifer was verified under steady-state and nonsteady-state conditions. The shallow aquifer was verified under steady-state conditions only. Approximate ground-water levels in 1983 in Indian Wells Valley were produced by the model to give planners an idea of the magnitude of future water-level declines. The computations were based on an initial set of projected pumpage figures. With this first estimate as a guide, the model will be used to evaluate various alternative pumping patterns.

Geohydrologic environmental studies

South Carolina.—G. E. Siple reported that a deep test well, drilled near the coast at Georgetown, S.C., corroborated conclusions based on an earlier test; most aquifers below the sands of Taylor-Austin age are saturated with brackish water. The well was drilled to a depth of 1,848 feet, the apparent top of the pre-Cretaceous basement surface. This is slightly higher than previous interpretations for the elevation of this surface in this area, and is almost 100 feet higher than that indicated by seismic data. The greatest development of the deep fresh-water aquifer system in the Charleston area in almost half a century took place within the past year or so when four wells were drilled to approximately 2,000 feet. Preliminary evaluation of these results indicated that aquifers in the predominantly Austin-Eutaw section are more permeable and contain water of lower salinity than do those in the Navarro-Taylor section in this general area. However, the specific capacities of these wells are generally lower than those of wells developed in sands of Navarro-Taylor-Austin age in other parts of the Coastal Plain. This may be due in part to the increased load of overlying rocks in this area where these aquifers occur at greater depths.

Florida.—J. M. Frazee is investigating optimum sustained-pumping rates for wells tapping the Floridan aquifer in the Cocoa, Fla., well-field area. During the past year, chloride content of the water in individual wells has increased as pumping time and withdrawals increased. Constant rates of pumping do not seem to result in as great a rise in the chloride concentrations as do alternate high and low rates of withdrawal. With each new period of high pumping rates, the chlorides again reach new record-high concentrations while periods of low pumping rates do not result in declines below the average rate of increase established over the past 4 years. Graphical analysis has been used to estimate optimum pumping rates to keep rises in chloride concentrations to a minimum. Pumping from the Cocoa well field amounts to 5.6 billion gal annually, and the cone of depression developed in the potentiometric surface of the Floridan aquifer is considerably below the water table. Studies are underway to determine the feasibility of using this head difference to siphon low-chloride water (20 mg/l) from the water-table aquifer into the Floridan aquifer. An experimental 3-inch siphon equipped with valves and flowmeter has been installed. If results are favorable, a siphon system may be installed at the well field to recharge the Floridan aquifer at selected sites where chloride concentrations of the water have risen above an acceptable level.

Arkansas, Texas, Louisiana, and Mississippi.—Maps showing sand percentage and thickness of the Carrizo Sand of Arkansas, Texas, and Louisiana, and of the Meridian Sand Member of the Tallahatta Formation of Mississippi were completed by J. N. Payne. These maps show a marked contrast in depositional pattern between the Carrizo Sand of Texas, the Carrizo in Arkansas and Louisiana, and the Meridian of Mississippi. In Texas the Carrizo is a blanket sand in which the thickness increases downdip from about 200 to 300 feet near the outcrop to 500 to 700 feet in a belt 5 to 15 mi wide extending from Webb County northeastward to Lavaca County, generally parallel to the orientation of the shoreline of the Carrizo sea. From Lavaca County northeastward to Sabine County, the Carrizo is generally 100 to 200 feet thick. In Arkansas and Louisiana the thickness of the Carrizo Sand is extremely variable, ranging from zero to more than 150 feet in a mile or less. The distribution of the thickness of the Carrizo in Arkansas and Louisiana and the Meridian in Mississippi suggests deposition in channels or valleys which had a general northerly trend. There was no deposition of the Carrizo Sand over many of the interchannel or intervalley areas in Arkansas and Louisiana.

Field determinations of chloride in water from the Mississippi River alluvial aquifer of northeast Louisiana, by M. S. Whitfield, indicated that, although the chloride concentration usually ranges from 3 to 100 mg/l, the occurrence of chloride in places exceeds 250 mg/l and may be as high as 1,900 mg/l. Some of the occurrences of high chlorides probably are related to former salt-water disposal pits (now buried); others probably are related to underflow of salt water from underlying Tertiary formations (mostly Cockfield); but for a few of the occurrences, neither of the explanations appears to fit the data.

During the delineation of saline ground-water subzones in Mississippi, G. J. Dalsin and Roy Newcome observed that the geothermal gradient in northwestern Mississippi differs from that elsewhere in the State. Bottom-hole temperatures from electric logs of deep oil tests were used to determine the geothermal gradient in each of the four quarters of Mississippi. Northwestern Mississippi has the highest geothermal gradient—approximately 0.78°C per 100 feet of depth. The remainder of Mississippi has a geothermal gradient of about 0.56°C per 100 feet. Factors possibly influencing the geothermal gradient are the following: deep-seated intrusions in northwestern Mississippi, salt domes in southern Mississippi, and near-surface proximity of Paleozoic consolidated rocks in northeastern Mississippi. It was also observed that the geothermal gradient is greater in the fresh-water section than in the saline-water section, irrespective of geographic area.

Gulf of Mexico.—Maps of the 200°F, 250°F, and 300°F isogeothermal surfaces in Tertiary deposits of the northern Gulf of Mexico basin show relief greater than 5,000 feet. Isogeothermal highs commonly reflect structural highs, but the amplitude of isogeothermal relief is a function of sediment-facies distribution. The depth of occurrence of the 250°F isogeotherm has an important relation to the salinity of water in aquifer systems because it indicates the depth at which clay mineral diagenesis should be virtually complete. The diagenesis of montmorillonite produces fresh water which escapes into adjacent aquifers, diluting their saline waters and driving them in the direction of escape from the deposits. As a consequence, there is good correlation among isogeothermal maps, maps of sediment-facies distribution, isosalinity maps, and structural maps for these deposits, according to P. H. Jones and R. H. Wallace, Jr.

Hydrology of basalts

The results of deep exploratory drilling in the Mud Lake region of the Snake River Plain in Idaho showed that ground water occurs under artesian conditions in a large part of the region at a depth of a few hundred feet below the regional water table. According to E. G. Crosthwaite, the artesian aquifers are composed of beds of sand and fine gravel and basalt flows; the water-table aquifers are made up of basalt flows. On the basis of the geology and hydrology observed, the Mud Lake region should be excluded from the Snake Plain aquifer for modeling purposes. Water-level measurements in new observation wells drilled near the west-central part of the Snake River Plain indicated that the gradient of the water table is more gentle in that part of the aquifer than was previously believed. East of the new wells, however, the gradient becomes steeper. The steeper gradient extends almost completely across the plain in a narrow band from near Arco to the vicinity of American Falls Reservoir, and occurs in approximately the same area as the Great Rift zone. This implies that the rift zone may have some control on the water-table gradient. Preliminary results of direct-current resistivity measurements, taken about 10 mi west of American Falls, indicated that the basalt of the Snake River Group is about 1,500 feet thick and is probably underlain by either sedimentary deposits or rhyolitic rocks.

Effect of water quality on hydraulic conductivity of clays

High-sodium water that is in approximate equilibrium with calcium carbonate may cause large reductions in hydraulic conductivity when introduced into materials that are not in exchange equilibrium with the solved ions in the water. A study by E. P. Weeks and W. W. Wood indicated that the permeability reduction is greater than that to be expected from the swelling and dispersion of clays in the material owing to sodium adsorption. Apparently, the increased calcium concentration resulting from exchange reactions leads to supersaturation with and precipitation of calcium carbonate that clogs pores in the material.

Production potential of Kisatchie Forest well field

J. E. Rogers reported that studies of the base flow of Spring Creek near Glenmora, La., indicate that about 11 inches of the rainfall that infiltrates the land subsequently appears as streamflow. If rainfall infiltration is uniform throughout the basin, the shallow sand and gravel of the terrace deposits should indefinitely sustain well yields of about 370 gpm for each square mile. The Kisatchie Forest well field at Alexandria, La., consists of 24 wells pumping from the terrace deposits. The effective area of influence of these wells probably is no more than 20 sq mi. Pumpage from the wells ranges from about 9 mgd to 13 mgd. In areas of heaviest pumping, withdrawals probably are exceeding recharge of the aquifer.

Evaluation of ground-water monitoring program in Wisconsin

R. E. Campbell and E. A. Bell evaluated the monitoring program to assist in management decisions on optimum use of the ground-water resources of Wisconsin. Thus far, ground-water levels from selected wells versus low flow in streams have been plotted, and a general scatter over a wide range has been found. If the plotting is grouped by season or month, the range of scatter is reduced. A family of curves was approximated through the grouped plottings of one set of correlations in a sandstone aquifer.

For discussion of ground-water hydrology in which model applications were used, see the section entitled "Model Studies," p. A141.

Hydrology of fractured rocks

The hydrology of fractured rocks is being studied by R. C. Heath in an effort to develop methods for predicting the long-term yield of fractured-rock wells. Pumping tests on wells in the Great Smoky Mountains National Park and along the Blue Ridge Parkway in North Carolina indicate two distinctly different hydrologic conditions. Drawdowns in pumping wells adjacent to perennial streams quickly stabilize as a result of stream infiltration. In contrast, the drawdowns in wells remote from streams have been observed to continue downward at a nearly constant rate during pumping tests of several days' duration. This is interpreted to indicate that the cone of depression is limited to a certain fixed area adjacent to the wells and that the water pumped is derived from seepage from the overlying saprolite. The results of step-drawdown tests on fractured rock wells, both adjacent to and remote from streams, show that as pumping levels increase, specific capacities decrease sharply.

Land-use effects

In a study by N. P. Dion to determine the effects of land use on the hydrology of shallow ground-water aquifers in the Boise-Nampa area of Idaho, comparisons were made between land-use and water-use conditions and hydrologic conditions in the shallow aquifers, as they existed in 1953 and in 1970. Some of the changes that occurred over the 17-year period include increases in (1) total population; (2) total irrigated acreage; (3) acreage irrigated with ground water; (4) population served by central water systems; and (5) population served by central sewer systems. A decrease was observed in the acreage irrigated with surface water. Land-use and water-use changes that occurred between 1953 and 1970 had the net effects of increasing ground-water withdrawals from the deep aquifer and increasing recharge to the shallow aquifers. In spite of the added recharge to the shallow aquifers, there has been no significant change in the amount of water stored in the shallow aquifers. This is largely due to the efficiency of the extensive network of natural and manmade drains in the area. A comparison of water-quality data for 1953 and 1970 suggests that no significant change in the quality of water in the shallow aquifers has occurred despite the abundance of septic tanks and the agricultural lands in the study area. Tests of water samples for the presence of fecal coliform bacteria and pesticides proved negative.

Ground-water network evaluation

L. C. Dutcher is doing research to establish criteria for designing a two-level data-collection system for ground-water hydrology in California for the period 1970 to 2000. The first level is intended to provide subjectively determined needs for data in the early phases of basin development, and the second level is intended to provide objectively determined needs for data in areas where development is advanced and ground-water basin models are available for use in designing the system. The second level requires that optimum data-collection programs be established. These programs will provide the highest accuracy-cost and value-cost ratios, including those determined in consideration of possible limitations of funds for data collection. The conceptual design rests on use of ground-water basin hydrologic and management models which use hydrologic and economic data for each basin, commensurate with decision variables, including the legal, political, and social factors that influence the decision-making processes of the ground-water basin managers. Then, through a form of sensitivity analysis, the types, quantities, and accuracy of data required to fulfill the management objective can be determined, and an appropriate data-collection program can be carried out in the basin.

Vertical ground-water velocity determination from temperatures

Ground water moving vertically transports heat by convection, causing curvature in the earth's thermal profile. Dimensionless plots of the temperature distribution in wells can be matched with published type curves to obtain solutions for vertical ground-water velocity if the thermal conductivity of the solid-fluid complex is known or can be estimated. M. L. Sorey and R. W. Stallman determined, from temperature studies in the San Luis Valley of Colorado and the Roswell Basin of New Mexico, that rates of upward movement through semiconfining beds were in good agreement with rates computed from pumping tests and water-budget methods. Limitations of the method result from instability in borehole fluids, measurement detail required, and magnitudes of flow that can be detected.

Definitions of ground-water terms

S. W. Lohman (r0454) reported on the work of the U.S. Geological Survey Committee on Redefinition of Ground-Water Terms. The use of ground-water terms as defined or redefined and of consistent units in all matters pertaining to ground-water movement is to be mandatory in reports of the U.S. Geological Survey.

Subsurface geophysics

Anomalies in topography, direction of ground-water movement, areal distribution of aquifer transmissibilities, lithofacies variations in valley-fill deposits, and the occurrence of earth fissures observed in the western part of the Salt River valley, Ariz., during the ground-water study by H. H. Schumann, and a gravity survey made by D. L. Peterson, led to the drilling of a deep exploratory test hole near Phoenix. The test hole confirmed the presence of a large salt mass, which is more than 3,600 feet thick. Additional geophysical work indicated that the top of the salt structure has horizontal dimensions of 1.5 by 4.5 mi, and that the top of the structure is 500 feet below the land surface.

SURFACE-WATER HYDROLOGY

Research on the occurrence and movement of surface water includes the mechanics of the flow process in stream channels and estuaries, the simulation of the variations of flow in time, and the generalization of streamflow data by correlation of flow characteristics with physical and climatic characteristics of drainage basins. The ultimate objective of this research is to provide methodology for the measurement of flow, the prediction of time of travel and dispersion rate of solids and solutes in streams, and the development of deterministic and statistical models of the variation of streamflow in time and space under both natural and manmade conditions.

Computer simulation of unsteady open-channel flow

By using measurements of discharge over tidal cycles to calibrate a mathematical model of the estuary based on the multiple-reach method of characteristics, Chintu Lai (r2515), F. H. Ruggles, Jr., and L. A. Weiss computed tidal flow throughout a 41-mi reach of the Connecticut River downstream from Bissel Bridge near Hartford, Conn., and generated diverse kinds of flow information for the tidal system such as flow velocity, stages, discharges, wave propagation, and the movement of injected particles. The variety of computer outputs available from this model suggests other potential uses such as generation of data for the study of diffusion that could be used in quality of water studies.

Diffusion in open-channel flow

An analytical solution to the problem of transverse diffusion of solutes in natural streams, developed by Nobuhiro Yotsukura and E. D. Cobb,[144] now provides a practical method for predicting the diffusion of solutes released continuously from a point or line source. The velocity distribution at several cross

[144]Yotsukura, Nobuhiro, and Cobb, E. D., 1972, Transverse diffusion of solutes in natural streams, *in* Dispersion in surface water: U.S. Geol. Survey Prof. Paper 582-C. [In press]

sections downstream from the source is the only field data required. The method has been checked against the observed diffusion at sites on several streams.

From a laboratory investigation of the relation of turbulent-diffusion coefficients to turbulence characteristics of the flow under a variety of conditions, R. S. McQuivey and T. N. Keefer found that longitudinal turbulent diffusion was as much as 20 percent and as little as 3 percent of the total dispersion process.

Dispersion in estuaries

By observing the dispersion of Rhodamine WT dye over a period of 55 days after a continuous injection for a period of 24.8 hr at a point on Colleton River upstream from Port Royal Sound, S.C., and by using these results in conjunction with theoretical models of dispersion processes, F. A. Kilpatrick and T. R. Cummings determined the ultimate pattern of concentrations to be expected in the Port Royal estuary from a continuous injection over an infinite period. They used the principle of superposition by which time-concentration curves for various points, based on concentrations resulting from the dye released during one tidal day, were integrated to provide curves of accumulated dye concentration from a hypothetical continuous injection at the same upstream point. As the dye-loss rate of the tracer is smaller than that of most solutes, they conclude that the computed ultimate concentrations of the tracer represents an upper limit of concentration to be expected from the continuous release of a comparable amount of other solutes. They also indicate that the results of their study could be used to estimate the effect of a continuous injection at other locations in the estuary that would be useful for planning purposes.

Mechanics of flow

From observation of turbulence of flow in pipe having smooth and rough boundaries, H. J. Tracy found that at the wall of the pipe the elongation of turbulent eddies in the direction of flow is affected more by the mean velocity than by the roughness, but that near the center of the pipe the elongation is little affected by either velocity or roughness. Turbulence fluctuations in the lateral direction are related to mean velocity over a greater distance from the wall in the rough pipe than from the wall in the smooth pipe. He concludes that the magnitude of the turbulence can be predicted within the limits of experimental error, using the magnitude of the local shear stress over the greater part of the central region of flow.

Channel hydraulics

By adapting the unit hydrograph technique to streamflow released from an upstream reservoir, V. B. Sauer (p. B259–B264) successfully routed outflow from the powerhouse at Toledo Bend Dam on the Sabine River (Texas and Louisiana boundary) to points 11, 37, and 50 miles downstream. The applicability of the technique depends on a linear storage-discharge relation and on a traveltime that does not vary appreciably with discharge.

By using a densimetric energy equation to calculate freshwater depth to the interface with the salt-wedge intrusion in the Chewaucan River–Abert Salt Lake system in Oregon, Nobuhiro Yotsukura found that the computed depth was within 0.5 foot of the observed depth to interface throughout the 3,300-foot reach. The interface depth varied from 1.8 feet to 3.8 feet, and the discharge was 200 cfs.

Recent studies by D. D. Harris to define water-surface profiles on the Rogue and Applegate Rivers in Oregon indicated vertical differences of as much as 4 feet between profiles computed by the step-backwater method, which assumes a level lateral water surface, and the documented marks of high water on the outside of a sharp bend in the river. He stresses the importance of considering this additional height on the outside of bends when defining areas of potential flooding.

By use of a mathematical model and numerical techniques, G. F. Pinder (r1446) and S. P. Sauer demonstrated that when a permeable aquifer is hydraulically connected to a stream, a flood wave is considerably modified owing to bank-storage effects, particularly in the lower segments of a long reach.

By relating the width, depth, and velocity of flow to measured discharge at each of 117 stream-gaging stations in or near Kansas, C. V. Burns[145] obtained values to use in relating these variables to the average flow and to the flows that are exceeded 10, 50, and 80 percent of the time. The latter relations can be used to estimate the width, depth, and velocity at any place on any natural-flow stream in Kansas where the drainage area is between 100 and 9,000 sq mi and where the indicated flow characteristic is known or can be estimated. The estimates of depth and velocity can then be used to compute the reaeration coefficient.

Rating large rivers

Comparison of (1) daily discharges computed from data recorded by an acoustic velocity meter, located on the Columbia River 3 mi below The Dalles, Oreg., and (2) the project discharges obtained from records of The Dalles project for a 5-month period indicated a standard deviation of departure of only 1.3 percent. Although the absolute accuracy of the data computed from the acoustic velocity meter's continuous recordings is no better than that of the current-meter measurements used for the basic calibration, Winchell Smith (r1789) concludes that instrumentation of this type will give reliable results for the flow of a large river subject to variable backwater. The acoustic velocity meter is based on the

[145] Burns, C. V., 1971, In-channel hydraulic geometry of streams in Kansas: Kansas Water Resources Board Tech. Rept. 8, 32 p. [In press]

principle that the flow of water along the path of an acoustic signal directed diagonally across a river increases the speed of the signal as it travels in one direction, and decreases the speed of the signal traveling in the other direction.

By use of current-meter measurements to develop ratings for flow through turbines, tainter gates, and navigation locks, and for flow over fixed spillways, methodology and computer programs have been developed that successfully compute continuous discharge records at several large multipurpose dams. Records of gate openings, turbine scroll-case pressure drops, lockages, and headwater and tailwater elevations are obtained from instruments developed by the Geological Survey. The methodology is now well enough developed to permit the writing of a general computer program that will use recorded data and developed ratings to compute the flow passing any structure having one or more of the indicated types of flow.

Streamflow generalization

Evaluation of the surface-water data program in each State revealed that the existing network of stream-gaging stations can be modified in view of the results obtained from generalized multiple-regression equations that relate streamflow characteristics to basin and climate characteristics. About 10 percent of the gaging stations now being operated were found not to be needed in obtaining the objectives set forth for the evaluation.

The greatest deficiency in streamflow information was found to be on regulated streams where dams and diversions have altered the natural flow pattern. Model studies are needed on 300 regulated stream systems to remedy this deficiency and to meet the objectives of the surface-water data program. Other areas of deficiency were found to be in estimating runoff from urban areas and in estimating low-flow characteristics at ungaged sites.

For many regions additional analyses will be required to provide estimates of streamflow characteristics of an accuracy equivalent to that obtainable from 10 years of record at all sites. The regressions were more successful in humid areas than in arid and semiarid areas, but even in humid areas low-flow characteristics cannot be generalized without some information being obtained at the site of the estimate.

As part of the surface-water data-evaluation project, computer files were established for the flow characteristics and basin characteristics at about 6,300 stream-gaging stations to make such data more readily available for use in future hydrologic studies. The file of annual peak discharge, for example, provides up-to-date flood data that can be made available to government and private users.

C. H. Hardison (p. C228–C236) found that the average standard error of prediction for generalized streamflow characteristics differs by more than 20 percent from the standard error of estimate of the regression when the streamflow characteristic used in a regression with basin characteristics has a time-sampling error that is larger than the space-sampling standard error and when the average interstation correlation coefficient is less than 0.25 or greater than 0.75. A low interstation correlation coefficient increases the accuracy of the estimates and a high one decreases it.

By use of data from frequency distribution curves of annual maximum precipitation for storm periods of selected length, S. E. Rantz (p. C237–C241) developed relations by which the amount of storm precipitation to be expected at any point in the San Francisco Bay region, California, at average intervals of from 2 to 100 years for storm periods of from 5 minutes to 60 days, can be estimated from the mean annual precipitation at the point. The relations, which are for use in local drainage design and in studies of land-slope stability, have standard errors that range from 10 to 20 percent of the estimated values.

Streamflow simulation

By consideration of theoretical statistical properties of correlated series of annual events, D. S. Crosby (r0106) (American University, Washington, D.C.) and Thomas Maddock III (USGS) developed a technique whereby streamflow records with various starting dates can be used to estimate the lag-one and cross-correlation matrices applicable to records for concurrent periods of observation. Maddock (r0967) and Crosby later extended the technique to produce new estimates of the expected values of mean annual flow.

D. R. Dawdy (r2142) (USGS), H. E. Kubic (U.S. Army Corps of Engineers), and E. R. Close (USGS) studied the relationship between the value of streamflow data for project design and the benefits foregone because of insufficient streamflow data. Stochastic simulation of a long-term hypothetical record for a sample station was used to determine a reservoir design based on full information. Shorter segments of the long-term trace were used to design other reservoirs under the same criteria. They found that for the station used in this study—a low mean flow, high variability station—the marginal value of streamflow data approaches the marginal cost at some time beyond the length of record of 100 years. The manner of evaluating streamflow data for project design was illustrated.

Flood risk

By fitting Pearson type III distributions to samples of annual flood peaks drawn from Pearson type III populations with selected skew coefficients, C. H. Hardison and M. E Jennings found that 50-year peak flows, estimated from samples of size 10 in the manner recommended for Federal agencies, have an average exceedance probability of 5.8 percent per yr if the samples are drawn from a population with a logarithmic skew coefficient of -1.0 as compared to 4.1 percent for samples from a log-normal population and 4.2 percent for samples from a population with a logarithmic skew coefficient of 1.0. Hardison and Jennings showed that these average exceedance probabilities provide a better basis for setting flood insurance premiums than does the exceedance probability of 2 percent obtained from the reciprocal of the 50-year recurrence interval. They computed similar average exceedance probabilities for sample sizes of 5 to 50, logarithmic skew coefficients of -1.5 to 1.5, and exceedance probabilities corresponding to recurrence intervals of up to 1,000 years.

CHEMICAL AND PHYSICAL CHARACTERISTICS OF WATER

Quality of ground water

Water samples were collected from 194 irrigation wells and 29 springs in Idaho by K. L. Dyer and H. W. Young, between March and September 1970, as part of a reconnaissance study of the chemical quality of the water in the Snake Plain aquifer. The majority of the sites were sampled at least twice and, although minor seasonal fluctuations were noted for some constituents, no well-defined trends could be established. The central part of the plain is underlain by water having a specific conductance of less than 300 μmhos/cm. Nearly all the irrigated areas, which occur along the eastern and southern margins of the plain, are underlain by water of higher conductivity, and in five localities the specific conductance values exceed 1,000 μmhos/cm. Chloride concentrations range from 7 to 325 mg/1, but most concentrations in the irrigated areas are between 10 and 160 mg/l. The nitrate distribution pattern is very similar to those of specific conductance and chloride; concentrations ranged from about 2 to 18 mg/l.

The occurrence of ground water in the lower Colorado River region is controlled by the geology and physiography in the three major geographic regions of Arizona, referred to in Arizona water-resources studies as the three water provinces—the Basin and Range lowlands province in the south, the Plateau uplands province in the northern half of the State, and the Central highlands province which runs east-west across the center of the State. According to L. R. Kister, the dissolved-solids concentrations in the ground water vary areally and with depth as the different water-bearing units are penetrated. Water in the alluvial deposits in the Basin and Range lowlands contains from less than 100 to more than 100,000 mg/l of dissolved solids, but concentrations generally are less than 1,000 mg/l. Water in the deposits in the mountains generally contains less than 1,000 mg/l of dissolved solids, except where the water issues from saline springs. The dissolved-solids concentrations in the water in the Colorado Plateau uplands in northeastern Arizona and northwestern New Mexico vary greatly; the dissolved-solids concentrations in about 1,500 water samples range from 90 to more than 60,000 mg/l. In the Central highlands the available chemical-quality data indicate that most of the ground water contains less than 1,000 mg/l of dissolved solids; however, several springs yield saline water—water that contains more than 1,000 mg/l of dissolved solids—to streams in the area. In the lower Colorado River region much of the ground water contains fluoride in excess of the amount allowable in drinking water. The large concentrations of fluoride in the ground water—fluoride in excess of about 2 mg/l—seem to be associated closely with andesitic to rhyolitic volcanic rocks and conglomerate of middle Tertiary age, schist of Precambrian age, and the weathering products of these rocks.

Twelve ground-water samples from wells in the Coastal Plain province of Georgia were analyzed for aluminum, arsenic, chromium, copper, lead, strontium, and zinc. T. G. Grantham found strontium and zinc present in every sample, lead in seven, copper in six, arsenic in three, and chromium in only one. The zinc ranged from 300 to 2,900 μg/l and the strontium from 100 to 560 μg/l. In the samples where the other elements were found, lead ranged from 10 to 20 μg/l, copper ranged from 10 to 30 μg/l, and chromium and arsenic were 10 μg/l. Aluminum was not found in any of the samples. Strontium was present in greater amounts in water from limestone aquifers in the eastern part of the coastal plain.

Several water and sediment samples were collected by R. L. Malcolm, L. A. Eccles, and Richmond Brown from playa lakes near Lubbock, Tex., to determine the feasibility of recharging playa-lake water into the Ogallala formation ground water. The playa-lake waters are generally of good quality with low conductivity and moderate organic content. The sediment concentrations are quite variable, ranging from 0 to more than 1 g/l, and are primarily silt-size aggregates of fine clay composed of montmorillonite, mixed-layered minerals, and lesser amounts of illite, kaolinite, and quartz.

Quality of stream water

R. A. Engberg reported (p. C215–C222) that analytical data for water samples collected at sites on 11 Nebraska streams indicate mean concentrations of nitrate ranging from 0.6 to 6.1 mg/l and mean concentrations of orthophosphate ranging from 0.35 to 2.0 mg/l. Nitrate concentrations and orthophosphate concentrations, to a lesser extent, show some correlation with population density, farm animal density, and percentage of drainage area planted to corn, but do not correlate with total dissolved-solids content of the water nor with water discharge.

Water from most streams in Puerto Rico is of calcium bicarbonate or calcium-magnesium bicarbonate type. However, in a potential copper mining area in the west-central part of the island, between Utuado and Adjuntas, R. T. Kiser reports that two streams, Río Viví and Río Pellejas, have relatively large amounts of sulfate in solution. At low flow, the water types are either calcium sulfate or calcium sulfate bicarbonate, while at high flow, the sulfate is less abundant. It is probable that the sulfate is derived from oxidation of pyritic material that crops out along the streams. The resulting sulfuric acid is neutralized by the alkalinity of the streams, but the water retains a residual alkalinity. The observed increase in sulfate between upstream and downstream stations on Río Pellejas is evidence that the sulfate-producing process continues downstream.

The concentration of trace elements in water samples collected at 37 stream sampling sites in New Jersey was measured by spectrographic techniques. P. W. Anderson (r1644) examined the data from fresh-water streams and found that the trace-element concentrations are highest in streams whose water quality is known to be greatly affected by man's activities, primarily industrial and municipal waste waters. However, high concentrations of iron and manganese relate better to vegetal decomposition or to ground-water inflow to streams. In general, the magnitude of concentration of the minor elements, in descending order, is as follows: Fe, Al, Sr, Mn, B, Ba, Cr, Cu, Ni, Zn, Pb, Co, Li, Ti, Rb, V, Mo, and Ag.

Recent investigations have been made by D. A. Curtiss of turbidity in Hills Creek Reservoir in Oregon. This work shows that even at low Jackson Turbidity Unit (JTU) readings, the water has a "milky" appearance, suggesting that the JTU may not be a good measure of turbidity from an aesthetic viewpoint. Depth profiles of dissolved oxygen, specific conductivity, and turbidity, were provided to the U.S. Corps of Engineers who operate the reservoir. From water-quality and other data it was determined that the turbidity was caused by montmorillonite in semicolloidal suspension. The montmorillonite evidently comes from volcanically derived rocks that form the reservoir banks.

Temperature of streams

Water-temperature records collected through September 1968 are summarized by J. C. Blodgett (r2021–r2023) for various streams throughout the State of California. Water temperatures are summarized by month, year, and for period of record. Reports will be published for each of the 11 hydrologic subregions of the State. Temperature records have been compiled for all stations operated by the U.S. Geological Survey, and also for many sites where data were collected by other Federal and State agencies. All data were processed by computer and the data stored for use in future analytical studies. Mean monthly water temperatures for the warmest and coldest months, and the recorded extremes for each of the temperature stations are summarized for each subregion. Confidence limits of the monthly means at the 95-percent level for the warmest and coldest months are determined for those stations with at least 3 yr of record. The accuracy of the data is evaluated, and a measure of the ability of point observations (both hand-held thermometers and thermograph probes) to indicate the mean temperature of a stream is given. An analysis, based on information from 180 temperature traverses of various streams, of the tolerance interval indicates that 99 percent of the point water-temperature observations should be within ±0.6°C of the mean stream temperature at the 95-percent confidence level.

E. J. Pluhowski found two predominantly ice-free reaches on Joes Brook in northern Vermont during January 1970. Both reaches are immediately below Coles Pond and Joes Pond, which are relatively large bodies of water. The ponds are used mostly for recreation; however, part of the outflow from Joes Pond is used for hydroelectric power. All other reaches of Joes Brook and all watercourses in the nearby Sleepers River basin were completely covered or bridged by one or more ice layers. Radiation losses from the streams were especially high at night under clear skies when energy losses of as much as 9 g-cal cm^{-2} hr^{-1} were recorded by net radiometers. Stream temperatures at seven sites on Sleepers River and at three ice-covered sites on Joes Brook were isothermal, averaging near 0°C at each site. Temperatures in the ice-free reaches on Joes Brook fluctuated less than 0.5°C diurnally—average temperatures in both reaches were about 1.0°C. Thus, the slight amount of heat added to the reaches below each pond was sufficient to produce the observed ice-free conditions. Ground-water inflow to the ponds and heat stored in the underlying sediments are the sources of this added heat energy.

Humic acids and organic matter

R. L. Wershaw and D. J. Pinckney (p. D216–D218) have isolated, by gel-permeation chromatography, a humic acid fraction which forms stable aggregates of different sizes in water solution. The average size of these aggregates measured by low-angle X-ray scattering decreases with increasing pH up to pH 7. At pH 7 all the particles are of a single size having a radius of gyration of 9.1 A. These data suggest that the humic acid fractions having high molecular weight are simply aggregates of particles having lower molecular weight.

R. L. Malcolm, L. A. Eccles, and P. W. McKinley have found that most of the color in many Florida streams is imparted by organic constituents in true solution. After pressure filtration of the waters through a partly clogged 0.45-μm filter, the cations and the complexed cations held by the dissolved organic substances are removed by elution through hydrogen-saturated exchange columns. The eluted organic substances are then concentrated by freeze-drying. The freeze-dried organic substances are light-brown solids similar to fulvic acids in elemental composition and chemical reactivity.

Pore-water solutes

R. V. James and Jacob Rubin in their study of hydrodynamic dispersion coefficients continued to test their new procedure for analyzing elution curves obtained with relatively short columns of porous medium, and for computing from these curves the coefficient of hydrodynamic dispersion of the medium, The analysis is concerned with miscible displacement of one solution by another, and takes into account the significant solute dispersion which takes place in the voids of the experimental apparatus, outside the porous medium being studied. For a series of displacement velocities, the procedure yielded computed elution curves which agreed with the observations much better than those based on the usual theory. The dispersion coefficients obtained were 10 to more than 30 percent higher than those yielded by the customary analysis. The largest differences were observed in the intermediate (5×10^{-4} cm/sec) and relatively high (3×10^{-3} cm/sec) displacement velocities.

RELATION BETWEEN SURFACE WATER AND GROUND WATER

Hydrology of Horseshoe Lake, Ark.

A study by A. G. Lamonds indicated that the stage of Horseshoe Lake, a 2,300-acre "old-river" lake adjacent to the Mississippi in east-central Arkansas, is affected by changes in the stage of the river and by the ground-water table in the vicinity of the lake. Interpretation of evaporation data, river-stage and lake-stage data, and water-level data indicated that average seepage out of the lake is 2,000 gpm, and may exceed 6,000 gpm during periods of low river stage. During the spring, when the stage of the Mississippi River and ground-water levels are high, the net seepage is into the lake but the rate of this seepage normally is low.

Removing sediments increases spring discharge

As part of a project to improve the habitat for trout in natural spring ponds discharging from glacial drift in Langlade County, Wisc., the hydrologic effects of dredging bottom sediments from the ponds are being determined. W. J. Rose found that after one of the ponds was dredged its discharge increased by 25 to 30 percent. Water-level measurements of an observation well in the aquifer immediately below the pond indicated a reduction in hydrostatic head. Continued monitoring will determine whether or not the increase in discharge will be sustained.

Ground-water inflow in relation to dewatering of Lake Apopka, Fla.

Lake Apopka, a 31,000-acre lake in central Florida, has undergone eutrophication in recent years. It is planned to dewater the lake with the expectation that a 5-foot layer of muck will dry on exposure and compact, and thus improve the ecology of the lake. Most of the potentiometric surface of the artesian aquifer underlying the lake is higher than the lake surface. Therefore, a potential for ground-water inflow exists under most of the lake, and ground water can be observed entering from the artesian aquifer through a spring in the southwestern corner of the lake. The feasibility of dewatering the lake depends on the magnitude of the ground-water inflow in relation to the capacity of downstream channels to convey the pumpage from the lake. Owing to channel conditions, the maximum allowable pumpage rate is tentatively set at 450 cfs.

Warren Anderson, by the water-budget analysis, found that the average head between the potentiometric surface and the lake surface was 6.4 feet greater during the wettest year of record than during the driest year of record. This difference is comparable to the increase in head that would be imposed by dewater the lake. The analysis indicated that dewatering the lake could cause a ground-water inflow of as much as 315 cfs, but that the actual rate would probably be considerably less. Dewatering of the lake therefore appears feasible.

Relation between recharge and overlying impoundment

A study of the recharge from Bivins Lake near Amarillo, Tex., was made by C. R. Gilbert as part of the artificial-recharge studies of the heavily pumped Ogallala Formation in the southern High Plains of Texas and New Mexico. Analyses of 12 yr of records of inflow and outflow from Bivins Lake showed that 77.6 percent of the initial storage plus total inflow seeped into the underlying Ogallala Formation. Moreover, if flow over the spillway had not occurred during a high-runoff period in 1951, about 90 percent of the initial storage plus total inflow would have seeped into the Ogallala.

Rates of seepage ranged from 3.1 to 33.8 acre-ft per day for this lake of generally less than 300 acres. Seepage is induced by almost continuous pumping from wells around the perimeter of the lake. The seepage rate was correlated with lake-surface area, viscosity, and difference in water levels of the lake and a nearby well. A least-square regression fitted to the data has the equation, $S = 1.06K^{0.595}$, where S is the seepage rate in acre-feet per day, and K is the product of the lake-surface area in acres times the difference (in feet) in water levels of the lake and a nearby well times 10^{-2} as a scale factor, divided by the viscosity of the lake water.

Sediment hinders recharge of floodwater

J. B. Gillespie studied the effect of sediment on recharge rates through temporary ponds behind flood-control structures. A pond (1,500 by 30 by 3.5 feet) was constructed in the channel of an ephermeral tributary to Walnut Creek in Rush County, Kans. The pond is underlain by 30 feet of unsaturated clayey to sandy silt. Sediment-laden storm runoff could be recharged through the pond to the water table at a rate of about 0.5 acre-ft per day. Recharge through the pond amounted to about 3.1 acre-ft per day when clear ground water was pumped from wells in the alluvium of Walnut Creek.

Effect of irrigation on chemical quality of ground water below Cedar Bluff Reservoir, Kans.

Applications of water from Cedar Bluff Reservoir to the land in the Cedar Bluff Irrigation District in Kansas have caused a tenfold increase in dissolved-solids content in the ground-water effluent to the Smoky Hill River since measurements began in 1964. According to R. B. Leonard, the specific conductance of the ground-water return flow is now about 1.4 times that of the specific conductance of the reservoir water. However, the ratios of individual-ion concentrations in the effluent to individual-ion concentrations in the reservoir water are disproportionately high for sodium and chloride, and low for magnesium, potassium, and sulfate. Therefore, salts present in the soil and in the ground water before irrigation began still determine the chemical composition of the effluent. Measurements of dissolved solids and specific conductance of the effluent are not yet a reliable indicator of the leaching requirement.

SOIL MOISTURE

The principles of soil-moisture retention and movement are a vital link in the chain of hydrologic principles being studied in efforts to understand and control our environment. The mechanisms involved in infiltration, evaporation, transpiration, and movement of water to the water table are being investigated in the natural environment as well as in the laboratory.

Soil horizons define wetting patterns

Characteristic patterns of wetting and drying in soils associated with desert shrubs and grasses have been defined by R. F. Miller, I. S. McQueen, and F. A. Branson. Soil horizons develop as a result of moisture movement. Therefore, soil horizons can be used to define wetting patterns. Moisture stresses in each horizon were found to vary between definable limits, so that by determining these limits for each horizon and the relationships between moisture stress and moisture content for each soil, the quantity of moisture involved in a wetting and drying cycle can be estimated.

Moisture content and moisture-stress relationships in soils

I. S. McQueen reported that analysis of data from a wide variety of soils indicate well-defined relationships between soil-moisture content and the moisture-retention forces in the soils. In the range between field capacity and the maximum stresses normally produced by plants the relationship between the moisture content and the log of the stress is a straight line.

Moisture-content graphs for various soils tend to intersect the zero moisture-content axis at about the same stress. The graph for a given soil can, therefore, be approximated by using the stress level as one point and a single moisture-stress determination as the other point. The moisture content-stress relationship between saturation and field capacity is highly changeable and cannot be approximated as well by laboratory methods.

Soil-moisture utilization changes resulting from vegetation modification

L. M. Shown and G. C. Lusby are studying changes in soil-moisture utilization resulting from conversion from big sagebrush to bluebunch wheatgrass in small watersheds at Boco Mountain, Eagle County, Colo. During the first year the adjusted evapotranspiration from the newly plowed and seeded basins was 35 percent less than from the sagebrush basins. The next year the evapotranspiration from the grassy basins was 17 percent less than from the sagebrush basins. However, the third year the evapotranspiration from the grassy basins was 51 percent more than from the sagebrush basins.

Studies of water or solute transfer in porous media

C. D. Ripple, R. V. James, and Jacob Rubin found that radial segregation of particle sizes occurs during the generally accepted procedures for packing uniform columns of powders. These procedures are commonly used in hydrologic laboratories in the course of water- or solute-transfer investigations with repacked soil or sediment samples. It was also found that the radial segregation observed can have a very considerable influence on mass-transfer processes in porous media.

New and more appropriate packing procedures were developed. These procedures largely eliminated the segregation process and yet produced bulk densities which are acceptable for hydrologic investigations. The procedures combine automatized, simultaneous powder deposition and tapping with damping of apparatus vibrations during the packing process.

EVAPOTRANSPIRATION

Evapotranspiration consists of the conversion of liquid water to vapor and is the sum of water transpired by plants and evaporation of water from the soil, water, snow, plants and artificial surfaces. Evapotranspiration accounts for approximately 70 percent of the 30-inch average annual precipitation in the United States, for nearly all precipitation in the arid regions, and for approximately one-third of the precipitation in the more humid regions. Thus evapotranspiration is a significant component of the hydrologic cycle.

The rate and quantity of evapotranspiration is primarily determined by the availability of water, and of energy, and by the rate of transport of water vapor from the evaporating surfaces.

Quantitative measurements of evapotranspiration are important in connection with water-resource planning, which includes prediction of water supplies available for domestic use, for irrigation of agricultural lands, for estimation of drought incidence, and for siting storage reservoirs and conveyance systems. Investigations of evapotranspiration by the U.S. Geological Survey include (1) studies of evaporation from lakes and reservoirs, (2) evapotranspiration from vegetated land surfaces, and (3) consumptive-use of water by phreatophytes.

Evaporation from small reservoirs in Texas

The climatic-index method used by the Texas Water Commission to determine monthly evaporation from reservoirs was evaluated by R. O. Hawkinson. Evaporation data based on the climatic index was evaluated by comparing it with evaporation data based on mass-transfer considerations. A statistical analysis of monthly evaporation rates determined by the two methods showed no significant difference between the two sets of data at the 5-percent level. Hawkinson concluded that both the mass-transfer and the climatic-index methods provide similar estimates of monthly evaporation rates from small reservoirs in Texas.

Mass-transfer equation for estimating evaporation

A variation of the mass-transfer equation to measure evaporation at a point on an open water surface was developed by G. E. Koberg. The parameters required for this equation are wind speed, air temperature, humidity measured at 2 m above the water surface, wind speed measured at 4 m above the water surface, and water-surface temperature. The ratio of wind speed between the 4- and 2-m heights are used to compute a diffusion factor for determining the rate of water vapor escaping to the atmosphere. This equation was applied to data from the Lake Hefner, Okla., study of 1950–51 and showed good agreement with results obtained by the water-budget method.

Correlation between lake seepage and ground-water levels

W. L. Yonts, Jr., reported that the preliminary analysis of the results of a 5-year-long hydrologic investigation of Lake Michie, in Durham County, N.C., yielded a mass-transfer coefficient, N, of 0.0038. This value of N agrees closely with the 0.0036 value obtained by Turner.[146] Comparison of the preliminary results of the water-budget and mass–transfer studies indicate that seepage into the 480-acre lake during the 5-year period has decreased. The average seepage rate into the lake for the 5-year period was about 1.9 cfs; however, the seepage rate from August 1964 to September 1966 averaged about 0.13 cfs. The lower rate of seepage into the lake, from August 1964 to September 1966, corresponds to the decline in the water level of a nearby observation well in Chapel Hill.

Estimating evapotranspiration with a digital model

R. C. Culler and R. L. Hanson are utilizing a digital model to evaluate water loss by evapotranspiration from a 15-mi reach of the Gila River flood plain above the San Carlos Reservoir in south-central Arizona.

The model design includes over 5,700 grid points with each point representing a 3.67-acre plot. Input to the model includes an average storage coefficient and the magnitude and spatial distribution of transmissivity for the gravel, sand, and clay deposits underlying the flood plain. The average storage coefficient was determined from measurements of soil-moisture change in the zone of water table fluctuations. An aquifer test and an analysis of the propagation of flood waves through the alluvial deposits provided estimates of transmissivity. Spatial variation of transmissivity was determined from measurements of the saturated thickness of the alluvium. The average storage coefficient obtained was 0.30 and the average transmissivity 200,000 gpd per ft.

The model is operated by applying, for a given period, a stress consisting of streamflow gains or losses and of an assumed evapotranspiration rate. The solution is obtained by varying the evapotranspiration rate until the computed declines approximate observed declines of the ground-water level. Preliminary tests of the model on a 5-mi section of the reach indicated an average evapotranspiration rate of 0.75 feet per month during the spring and summer of 1964.

Evapotranspiration by phreatophytes

O. M. Grosz[147] studied seasonal water use by saltcedar and rabbitbrush, grown in plastic-lined evapotranspiration tanks near Winnemucca, Nev. Evapotranspiration during the 1969 and 1970 growing seasons averaged 14.9 and 12.9 inches, respectively, from three rabbitbrush tanks with the water level about 8 feet below the soil surface. Forty-seven percent of the evapotranspiration from these tanks (7.0 and 6.1 inches in 1969 and 1970) was draft from ground water, 4.8 inches each year was soil-water depletion, and the remainder (3.1 and 2.0 inches, respectively, in 1969 and 1970) was from precipitation.

Average evapotranspiration from the three saltcedar tanks, with the water level about 3 feet below the soil surface, was 17.2 inches during the 1970 growing season. Of this, 76 percent (13.1 inches) was draft from ground water, 23 percent (3.9 inches) was from precipitation, and only 1 percent (0.2 inch) was from soil-water storage.

LIMNOLOGY

Average dissolved oxygen

Available methods of obtaining dissolved oxygen (DO) data at water-quality network stations have limitations of high cost,

[146]Turner, J. F., Jr., 1966, Evaporation study in a humid region, Lake Michie, North Carolina: U.S. Geol. Survey Prof. Paper 272-G, p. 139-142.

[147]Grosz, O. M., 1971, Progress report on studies of evapotranspiration by woody phreatophytes for 1970 growing season, *in* Twelfth annual progress report, Humboldt River Research project: Nevada State Dept. Conserv. and Nat. Resources. [In press]

difficulty of sampling for day-night (diel) changes, and lack of comparability of data. The diel average DO concentration is better than a single daytime measurement for comparing DO conditions at different locations. Simple devices called DO integrators were developed by K. V. Slack (r2510) for determining average DO concentration at stations that could be visited only at intervals of days or weeks. The integrators are closed water-filled containers which contact the environment through semipermeable diffusion barriers. Molecular oxygen diffuses through the barriers until oxygen pressures inside and outside the containers are equal. The rate of equilibration is so slow that diurnal and other short-period fluctuations in DO are smoothed out and the integrator DO value equals the average DO of the environment. Like membrane-covered electrodes, the internal solution is protected from many substances which would interfere with chemical determinations of DO.

Because the diel oxygen curve is sinusoidal, an average of the highest and lowest values approximates the integrated average DO. Therefore, the late afternoon DO concentration and the diel average provide an estimate of the nighttime extreme DO concentration. Eighty-two percent of predicted nighttime extremes were within 1 mg/l of the observed values for published records from many different environments. It was concluded that DO integrators, used with measurements of instantaneous DO concentration, can significantly increase the interpretation of network DO data.

Oxygen deficit of lakes in Washington

During the spring the waters of most lakes are well mixed and aerated by wind-driven currents. The oxygen content is high, and the lake is of a uniformly low temperature. Later, during the summer, the lake water is separated into three distinct layers of differing density dependent upon their temperature characteristics. This condition is called thermal stratification. Because the lowermost layer, or hypolimnion, is isolated from surface light and air, its supply of oxygen cannot be replenished as long as stratification persists. The rate at which the oxygen content of the hypolimnion decreases during thermal stratification is called the oxygen deficit. It provides a relative estimate of the rate of organic decomposition in the hypolimnion.

M. R. Collings, G. C. Bortleson, G. T. Higgins and G. W. Hill determined from a sequence of dissolved-oxygen profiles, the relative oxygen deficit in several well-stratified western Washington lakes. It was found that the oxygen-uptake rate ranged from 0.0081 to 0.0092 mg/cm^2 per day for two oligotrophic high-altitude lakes to 0.051 mg/cm^2 per day for American Lake, which is situated in a low-altitude, urban drainage basin near Tacoma. This rate is similar to the 0.060 mg/cm^2 per day observed for Lake Washington near Seattle in 1965. Highly transparent Gravelly Lake, also near Tacoma, showed an oxygen uptake rate of 0.018 mg/cm^2 per day. In other western Washington lakes studied, the oxygen uptake values were 0.017, 0.024, 0.027, and 0.031 mg/cm^2 per day. The relative oxygen deficit appears to be a useful measure of differences or of changes in the productivity of lakes.

Characteristics of a marine coastal lake

Lake Earl, Del Norte County, Calif., is a shallow coastal lake near the California-Oregon border. The lake is presently stabilized by a series of dunes estimated to be between 1,400 and 1,600 yr old. Cores from conifer trees growing on the dunes indicated an age of from 85 to 187 yr for the trees. The lake receives inflow from one main tributary, Jordan Creek, but inflow also derives from the Smith River during floods and from the Pacific Ocean during flood tides. The variety of waters entering Lake Earl results in a horizontal gradient in salinity. R. C. Averett and E. J. Helley found that the salinity in summer ranged from about 18 parts per thousand (about half that of sea water) near the mouth of Jordan Creek to about 22 parts per thousand near the western (seaward) border. The lake water is well mixed vertically, probably by currents generated by the prevailing onshore winds. The study disclosed that dissolved oxygen was at saturation. Concentrations of nitrate and ammonia were low, but organic nitrogen ranged from 0.31 to 0.87 mg/l. Sediment cores from the lake bottom contained about 5 to 14 percent organic matter.

Nitrogen and phosphorus compounds in Clear Lake, Calif.

In a study of Clear Lake, Calif., W. D. Silvey compared the concentrations and total loads of nitrogen and phosporus that entered and left the lake from June 1968 through May 1969. It was estimated that a mean of 164 tons of nitrate nitrogen, 318 tons of organic nitrogen, and 82 tons of phosphorus entered the lake. In the same period 214 tons of nitrate nitrogen, 615 tons of organic nitrogen, and 103 tons of phosphorus left the lake. The study period encompassed a year of unusually high precipitation and runoff, resulting in discharge from the lake in early January. In "normal" years water is not discharged from the lake until the spring irrigation season.

Phytoplankton changes in Lake Okeechobee, Fla.

Increased concentrations of phytoplankton to bloom levels and the change of dominant species indicate a change in biological activity in Lake Okeechobee, Fla. B. F. Joyner found that phytoplankton counts never exceeded 4,600 cells/ml during a study period beginning in January 1969. The average concentration of phytoplankton in the lake in July 1970, however, was 32,300 cells/ml, with a high concentration of 106,800 cells/ml in the western part of the lake. The average concentrations decreased to 25,400 cells/ml in October, but a high concentration of 108,500 cells/ml remained in the western part of the lake. In January 1971, the phytoplankton concentrations increased in the northwestern part of Lake Okeechobee to a high estimated count of 473,700 cells/ml, but decreased in other areas.

The dominant phytoplankton organism changed from *Pediastrum simplex*, a green alga, to *Aphanizomenon holsaticium*, a blue-green nuisance species. One encouraging sign, however, is that all the *Aphanizomenon* observed in the July and January samples were small and atypical in appearance, perhaps indicating that nutrient conditions in the lake are favorable for reproduction but unfavorable for optimum growth of algae.

Water quality in Flaming Gorge Reservoir, Utah and Wyoming

Initial water-quality sampling of Flaming Gorge Reservoir on the Green River in Utah and Wyoming disclosed physical and chemical stratification. Dissolved oxygen, specific conductance, and water temperature were measured between the surface and bottom of the reservoir by E. L. Bolke and K. M. Waddell using in situ sensors. In October 1970 the epilimnion or mixed surface layer extended to a depth of about 30 m. The highest temperatures (10° to 12°C), highest dissolved oxygen (5 to 7 mg/l), and lowest specific conductance (600 to 700 μmhos) occurred in this layer. Below the epilimnion, a stratum of water about 23 m thick, the thermocline or metalimnion, exhibited rapid change in temperature which ranged from 10° to 4°C as the depth increased. Dissolved oxygen decreased from 5 mg/l to 2 mg/l, and specific conductance ranged from 700 to 800 μmhos. In the hypolimnion, between the metalimnion and the bottom, water temperature was about 4°C, the temperature of maximum density. Dissolved oxygen ranged from 2 mg/l at the upper boundary of the hypolimnion to zero at the bottom. Specific conductance reached nearly 1,000 μmhos. Most of the shallow upstream part of the reservoir was included within the epilimnion, although water temperatures and dissolved-oxygen values were slightly higher and specific conductance values slightly lower than in the deep, downstream section.

Chemical stratification apparently persisted throughout the winter; in April 1971 the distribution of dissolved oxygen and specific conductance in the deep section were about the same as they were in October 1970. However, the surface water was only about 1°C warmer than the water at the bottom which remained 4°C.

Effects of air injection on Lake Cachuma, Calif.

Compressed air was injected into Lake Cachuma, Calif., for an 8-month period during 1968, and the effect on water quality was studied. In a summary of data collected during the 4-year investigation, 1966–70, M. W. Busby concluded that the effects of air injection on the lake were minor. Water temperature distribution showed the greatest change. The onset of thermal stratification was delayed about 2 months, and, when established, the mean depth of the upper circulating zone was 10 to 15 m deeper than it was without air injection. The greatest positive effect of air injection was the doubling of the part of the lake with sufficient oxygen to support fish life. However, a zero dissolved-oxygen zone, although smaller, still developed below a depth of 30 m. Nutrients, phytoplankton, and evaporation apparently were unaffected by the treatment. Air injection at the rate of 600 to 700 cfm (283–300 liters/sec) into a reservoir containing 171,200 acre-ft (211×10^6 m^3) of water, was not sufficient to effect complete physical or chemical destratification.

Anticipated characteristics of a new reservoir

The chemical and biological characteristics of Bald Eagle Creek, Pa., were investigated in order to make a prognosis of the water quality of Foster Joseph Sayers Reservoir, a shallow recreational and flood-control impoundment that will be initally filled in 1971. Evaluations, by H. N. Flippo, Jr., of the collected data indicate that the reservoir will be stratified in summer, at which time the water of the hypolimnion at the bottom of the reservoir will be deficient in oxygen. Water-borne nutrients are expected to cause nuisance growths of algae and aquatic vascular plants. High densities of fecal-coliform bacteria, which often exceed 5,000 per 100 ml in Bald Eagle Creek, also are expected to lessen the recreational utility of the reservoir.

Association of bacteria with blue-green algae

In a study of symbiotic relationships between blue-green algae and bacteria, P. E. Greeson and T. A. Ehlke have successfully cultured twelve species of bloom-forming nuisance algae isolated from natural (lake) populations. The bacteria most commonly associated with the algae are *Pseudomonas*, *Bacillus*, and *Flavobacterium*, although *Aeromonas* and *Achromobacter* also were abundant. Preliminary results suggest that the algal species studied have a definite bacterial flora in each lake, but that the bacterial flora for a given algal species may be different from lake to lake.

PLANT ECOLOGY

Observations on growth rate of saltcedar

Observations on the growth rate of saltcedar were made near Buckeye, Ariz., by T. E. A. van Hylckama (r0851) in the study on water use by saltcedar. In an evapotranspirometer, saltcedar that was cut at a height of about 50 cm showed an average increase in twig length per day of 25 mm during the period April through June. On individual branches an increase of more than 50 mm/day was observed. Cucumber sprouts can grow 5 mm/hr, and bamboo shoots have been known to grow 30 mm/hour. Saltcedar, under favorable circumstances, seems to be a competitor in the field of fast-growing plants.

Ecological investigations in the Florida Everglades

Aerial photography and ground transects are being used by B. F. McPherson to detect changes in aquatic vegetation in

Conservation Area 3 of the Everglades west of Miami, Fla. Initial transects in July and December 1970 indicate that relatively large seasonal changes occur in the emergent vegetation. These large seasonal changes will make it difficult to detect long-term vegetative changes. Ground transects also have indicated that, in general, average vegetative biomass increases with water depth.

Data on pesticides showed relatively low concentrations in the water (less than 0.25 μg/l) and sediment (less than 34 μg/kg) in August 1970. However, PCB Aroclor, a petroleum derivative of benzene and chlorine used in a variety of industrial materials such as plasticizers, insulating fluids, and flame retardants, was detected in two bottom samples in concentrations of 76 and 1,100 μg/kg.

Dating hydrologic extremes by tree-ring growth

It appears possible to identify years of extreme growth-season precipitation or streamflow from tree rings of extreme size. Utilizing material collected in south-central New York, R. L. Phipps found that years of extremely high or extremely low growth-season precipitation and years of extremely high growth-season streamflow corresponded with years of extreme tree growth of some tree species growing in certain habitats. Identification of years of extremes appeared reliable as long as a general correlation between overall growth-season soil moisture and precipitation or streamflow existed. Thus a year of high growth-season precipitation resulting from grossly atypical temporal distribution of rainfall was not identifiable from tree growth by these methods.

NEW HYDROLOGIC INSTRUMENTS AND TECHNIQUES

MISCELLANEOUS INSTRUMENTS AND TECHNIQUES

The U.S. Geological Survey is presently involved in several water-resources investigations which require up-to-date, accurate information on bed contours of coastal and inland waterways. G. F. Smoot reported the development of a bathymetric surveying system to acquire this needed information. A small outboard watercraft, fitted with appropriate electronic equipment, is used to survey a body of water. The functional makeup of the system is simple but consistent with the needs of automated data collection. A system control unit programs the data from the digital equipment (a real-time clock, a depth sounder, and an electronic position-fixing system), so that a data record on magnetic tape that is suitable for computer processing is provided. These data, along with a tidal record, is processed into profile charts through the use of a computer contouring program.

Accessories for use with manometers

H. O. Wires reported the development of an automatic air-bleed system for use on turbine piezometer taps. This development has greatly improved the reliability of records obtained from turbines with the differential pressure manometer. Several accessory items have also been developed for use with stage-recording manometers. These items include a temperature-correcting device and a crystal interval timer, having a visual time reference.

Equipment for measuring pressure and taking samples in geothermal wells

R. O. Fournier and A. H. Truesdell (p. C146–C150) found that flexible stainless-steel tubes may be used to measure down-hole pressures in geothermal wells by balancing a gas pressure in the tube against the hydrostatic pressure external to the tube. The bottom of the tube is fitted with a check valve to prevent water in the hole from entering the tube, but allows gas in the tube to escape when the internal pressure exceeds the fluid or gas pressure outside the tube by an amount sufficient to overcome force of the spring holding the valve closed. Pressure profiles have been measured in wells both at static and flowing conditions. Down-hole enthalpies can be calculated from the variation in slope of the resulting depth-versus-pressure graphs.

Fournier (p. C151–C155) also reported designing and field testing a sampling device with an internal volume of 500 ml to collect liquid and gas samples in geothermal wells where both steam and water are present. A long, flexible stainless-steel tube serves as the support cable. The sample device is lowered in the open position and fluid flows through it during its descent. Closure is accomplished by nitrogen gas pressure applied from the surface through the flexible tube to a piston and plunger within the sample chamber. Continued application of nitrogen gas pressure during withdrawal of the device prevents leakage caused by changing conditions of temperature and pressure. The sampling device has been used successfully to collect water and gas samples from research holes drilled in hot-spring areas of Yellowstone National Park, Wyo. The deepest well was 332 m and had a bottom-hole temperature of 240°C.

Use of videotape in well surveys

J. E. Eddy reported participating in a survey of 14 wells located in an area extending from Cheyenne, Wyo., to a site 140 mi away. A television camera was lowered into the wells, and wall features of the wells were recorded on 1-inch videotape that can be used for later investigations. This tape is compatible with tape recorders used by educational institutions or broadcast stations.

Use of well-logging data to delineate hydrologic characteristics of rocks

L. M. MacCary (p. D190–D197) found that data from resistivity and neutron logs of the Lockport Dolomite in northwest Ohio can be used to estimate water quality and formation porosity if sufficient supporting data are available. The method of using resistivity logs has been previously applied to granular aquifers but, when applied to carbonate aquifers meeting the specified criteria, semiquantitative data were obtained.

W. S. Keys and R. F. Brown (p. B270–B277) reported the use of neutron, natural gamma, and gamma-gamma logs to delineate the hydrologic characteristics of the Ogallala Formation in Texas. Natural gamma and neutron-epithermal neutron logs clearly distinguish clay-rich beds and are used for stratigraphic correlation. Radium-potassium and radium-thorium ratios, measured on core samples, are related to the calcium carbonate content of the sediments. Natural gamma spectra are being measured in boreholes, and it is hoped that this technique will enable identification of caliche zones that have a lower permeability.

Hydrologic applications of an airborne fluorometer

G. E. Stoertz and W. R. Hemphill reported that studies of current dynamics and dispersion by use of fluorescent dyes, detection of water pollutants by the fluorescence of chemical and organic wastes, and studies of the spatial and temporal distribution of marine-plant chlorophyll are all possible hydrologic applications of an airborne fluorometer being developed in cooperation with the National Aeronautics and Space Administration. The instrument being used in this unique research program is an electro-optical sensor designed to remotely detect substances that fluoresce when irradiated by sunlight. The prototype sensor, known as a sodium-D_2 Fraunhofer line discriminator (FLD) was designed to sense fluorescence at the sodium-D_2 line (5,890 A). It has proven useful in an airborne or shipboard fluorescence radiometer, or fluorometer, capable of measuring substances that fluoresce amber, such as rhodamine dyes.

The prototype sensor has recently been converted to sense deep-blue fluorescence at the hydrogen-F line (4,861 A) and conversion to the deep-red hydrogen-C line (6,563 A) is underway. Spectrofluorometer analyses of a large number of fluorescent materials have shown that numerous natural substances emit appreciable fluorescence at 4,861 A, in the deep-blue part of the visible spectrum. Among these are pulp- and papermill effluents which contain fluorescent lignin sulfonates, phosphate rock from rich deposits in Saudi Arabia, petroliferous sandstone from deposits in Colorado (Green River Formation) and Utah (Moenkopi Formation), some limestones, nitrate caliche from Chile, crude oil from the Santa Barbara, Calif., oil spill of 1969, sardine oil, dishwashing detergent, scheelite-bearing tungsten ore, and a variety of minerals, some of which are common in surficial evaporite crusts (for example, gypsum and aragonite).

Current research is exploring hydrologic applications of this new technique, with emphasis on detection of water pollutants such as pulpmill waste. The hydrogen-C sensor will be designed to detect the deep-red fluorescence of chlorophyll, commonly found associated with phosphate–and nitrate-rich pollutants in rivers and estuaries, and it is hoped that it will find application to agricultural or forestry research as well. The technique may also find future geologic applications such as the sensing of some of the aforementioned minerals and rocks.

Equipment for measuring sediment concentration

J. V. Skinner and J. P. Beverage have developed and tested a special neutrally buoyant container for use in the laboratory as a device for rapidly measuring sediment concentration. The method, which eliminates decantation and drying, gives values which are within 100 mg/l of true values.

Accuracy can be improved by adding temperature controls. They also report that additional controls for automatic pumping samplers have been developed, and a large-volume point and depth integrating sampler for use in deep water is in the final design stage.

Equipment for measuring evaporation

A. M. Sturrock, Jr., reported that a new direct-current motorized psychrometer has been developed to measure vapor pressures at remote raft locations on reservoirs. Also, an X-3 insulated pan, developed by the U.S. Weather Bureau, was used to aid in correlation of radiation values obtained from standard instruments. Results for evaporation measurements should improve with the use of these new instruments.

COMPUTER TECHNOLOGY IN WATER-RESOURCES STUDIES

Use of the digital computer has become so widespread in water-resources studies that most researchers use it routinely. Only current highlights are indicated below.

Finite-difference techniques make it possible to approximate and directly solve partial differential equations. In water-resource studies, a number of partial differential equations which describe the following phenomena are of interest: (1) the unsteady flow of water in a stream channel, (2) the unsteady flow of ground water in an aquifer, and (3) the unsteady transport of chemical constituents in either a ground-water or surface-water system.

Flow of surface and ground water

Chintu Lai and R. A. Baltzer developed numerical techniques, based upon finite-difference approximations, to solve for the transient flow of surface water in a stream or estuary. This work is being extended to two space dimensions.

Digital techniques for the analysis of the transient flow of ground water in a single artesian aquifer are well established. Digital ground-water models are being used widely for the analyses of field problems in such widely scattered areas as Arizona, California, Colorado, Georgia, Hawaii, Kansas, Kentucky, New Jersey, New Mexico, Virginia, Washington, and Wisconsin. The digital ground-water model has been extended by J. D. Bredehoeft and G. F. Pinder to the solution of the nonlinear equations which describe the flow in a water-table aquifer, and to the solution of problems involving multilayer aquifer systems. The analyses for both these solutions are based on iterative finite-difference techniques.

J. A. Skrivan and H. H. Tanaka have also developed a similar digital technique for the analysis of a two-aquifer ground-water system. Skrivan and Tanaka are engaged in the analysis of the effect of irrigation on ground water in the Columbia Basin Irrigation Project, in central Washington.

Similar finite-difference methods are used to solve the equation of transient water flow in the unsaturated soil zone. Jacob Rubin and C. D. Ripple are using numerical methods for the analysis of one- and two-dimensional unsaturated flow.

The hydrologic studies group under the direction of H. C. Riggs and S. P. Sauer has developed a system of computer programs which accounts for the effects of stream regulation. This allows either a reconstruction of the natural stream flow or a prediction of the effects of regulation.

G. F. Pinder and S. P. Sauer have coupled and solved the dynamic equations of streamflow and ground-water flow. This method allows one to study the coupling between streams and aquifers and to accurately describe the effects of bank storage.

Movement of chemical constituents in water

The transport equations for the movement of chemical constituents in either a ground- or surface-water system can also be solved by numerical methods. G. F. Pinder and H. H. Cooper, Jr., solved the miscible transport equation with dispersion for the transient position of a salt-water front in a ground-water system. The method is sufficiently general that it can be extended to the solution of the transport equations in any system. The solution first requires that at any time step the flow equations are solved for the velocity distribution; the solution is then followed by a solution of the transport equation. Based upon these methods, a general chemical model has been developed by J. D. Bredehoeft.

Rainfall-runoff relations

Work is continuing on a rainfall-runoff model by P. H. Carrigan, Jr., and R. W. Lichty. Although the model is in use, it still is in the developmental stage. As part of this work, Carrigan has developed a streamflow generator for monthly flows at an ungaged site. N. C. Matalas and J. R. Slack have developed a daily streamflow generator for a gaged site.

SEA-ICE STUDIES

Investigators of the U.S. Geological Survey have used a three-phase approach to the problem of sea-ice dynamics: (1) remote sensing in polar regions, (2) participation in international expeditions to the Arctic Ocean, and (3) development of numerical models for ice-covered oceans.

W. J. Campbell planned a series of overflights by the National Aeronautics and Space Administration (NASA) Convair 990 remote-sensing aircraft over the Beaufort Sea in March 1971 as part of the Spacecraft Oceanography Project. A. D. Moen took part in the five Convair 990 flights over the Arctic Ice Dynamics Joint Experiment (AIDJEX) ground-truth site at lat 74° N., long 135° W.

The AIDJEX project, an international, interagency, and interuniversity group formed to study arctic-ice dynamics and energy-budget problems, has mounted two major international expeditions to the Beaufort Sea in the last 2 yr. The sea-ice project office in Tacoma, Wash., is intimately involved with the AIDJEX project and is presently cooperating with it in remote-sensing and theoretical studies. Overflights of the AIDJEX expedition site were made by U.S. Coast Guard and Navy aircraft, and these flights were coordinated with the NASA flights by the project office. According to W. J. Campbell, three kinds of remote-sensing data of sea ice were obtained: (1) large-scale synoptic sequential imagery of sea ice using SLAR (side-looking airborne radar) and microwave equipment, (2) mesoscale imagery of sea ice over an existing strain network using SLAR and laser profilometer, and (3) microwave emissivity in situ measurements of the sea ice coupled with concurrent mesoscale strain measurements.

L. A. Rasmussen and W. J. Campbell have developed a new model for sea ice which differs from earlier models that treated the ice as a thin Newtonian viscous fluid. It is a steady-state numerical model for the entire Arctic Ocean in which the ice is assumed to flow under the action of four forces: air stress, water stress, Coriolis force, and the internal ice stress. Three different viscous ice constitutive laws are alternatively assumed for the internal ice stress: (1) quasi-anisotropic, (2) isotropic with a variable shear viscosity dependent upon the sign of ice divergence, and (3) isotropic with constant shear and bulk viscosities.

ANALYTICAL METHODS

ANALYTICAL CHEMISTRY

Microprocedures for the determination of carbon dioxide, aluminum, and ferrous iron

In a continuation of a series of publications on microanalysis semimicroanalysis of silicate minerals, Robert Meyrowitz has described determinations of carbon dioxide, aluminum, and ferrous iron. Carbon dioxide is determined after a hydrochloric acid decomposition by a gravimetric microprocedure (Meyrowitz, r0178) using a modified Schroedter alkalimeter as a reaction flask. The carbon dioxide, after purification, is absorbed in a tube containing Ascarite (sodium hydroxide on asbestos). Aluminum is determined (Meyrowitz, r0617) with pyrocatechol violet after a sodium hydroxide fusion of the sample in a gold crucible followed by dissolution of the melt in hydrochloric acid. Iron and titanium, the only elements likely to interfere, are added to the aluminum standard solutions to compensate for the presence of these elements in the sample. Ferrous iron is determined (Meyrowitz, r1326) in a sample after fusion in an argon atmosphere, using sodium metafluoborate as flux. The melt is dissolved in an excess of a standard dichromate solution which is subsequently titrated with ferrous ammonium sulphate. A sample blank must be carried through the entire procedure.

Colorimetric determination of iodine in rocks

A rapid and sensitive colorimetric method for the determination of microgram amounts of iodine in rocks was developed by F. S. Grimaldi (r0932) and M. M. Schnepfe. Iodide is leached from a mixed sinter that includes magnesium oxide to retain the silica in the residue. Mixed iodate and iodide is oxidized completely to iodate, reduced with stannous sulfate to iodide, and the iodide oxidized to iodine with sodium nitrite. Iodine is extracted with carbon tetrachloride and measured at 517 nm. The procedure provides for the presence of various forms of iodine such as iodide or iodate or iodide bound organically. As little as 1 ppm iodine in the presence of milligram amounts of chloride and bromide can be determined rapidly on a 1-g sample. The method has been applied to the determination of iodine in hundreds of rocks of various descriptions.

Determination of traces of osmium and ruthenium

A catalytic-rate procedure for the simultaneous determination of nanogram amounts of osmium and ruthenium in mixtures was developed by M. H. Fletcher. The method gives good results for both osmium and ruthenium in pure solutions when the Os-Ru weight ratio ranges from 0.06 to 27.2. The method can serve as a final step in a procedure for rock analysis if the two elements can be isolated together.

Spectrophotometric determinations automated

A system to automate the acquisition of spectrophotometric data was designed, constructed, and put into routine use by the U.S. Geological Survey for determining silicon, aluminum, titanium, iron, phosphorus, and manganese. The system developed by Leonard Shapiro and C. J. Massoni[148] uses commercially available components and a sample changer designed and built by the Geological Survey. The sample changer accommodates seventy-two 100-ml beakers arrayed in three concentric circles. The solutions to be measured are placed in the sample changer, and, after the digital concentration readout is adjusted to read the concentration of the standard solution in percentage, the sample solutions are sequentially sucked into the photometer cell. The printed results, in percentage concentration, are produced at the rate of 72 in 14 minutes. The results are comparable in accuracy with those produced by careful manual measurement. The measurements are made more rapidly and all reading and arithmetic errors are eliminated.

[148]Shapiro, Leonard, and Massoni, C. J., 1972, An automated spectrophotometer, *in* Geological Survey Research 1972: U.S. Geol. Survey Prof. Paper 800-B. [In press]

Lithium metaborate flux for silicate analysis

Lithium metaborate is coming into general use as a flux for silicate analysis. The commercially available product has often been of poor quality, frequently unsuitable for analytical work. C. O. Ingamells (r0904) described the preparation of the reagent by heating a mixture of lithium carbonate and boric acid, and gave the details for its purification. He also presented a detailed summary of the uses and handling techniques for this valuable flux.

Analysis of chromite by atomic-absorption spectrophotometry

Atomic-absorption spectrometric methods were applied to the analysis of chromite and chrome ores by J. J. Warr and J. I. Dinnin. A nitrous oxide-acetylene flame was used for the direct determination of aluminum in an acidified solution of the mineral. An acetylene-air flame was used for determining magnesium, calcium, and manganese. The direct nature of the procedures eliminates the need for time-consuming and potentially hazardous mercury-cathode separations.

Determination of low concentrations of lead in rocks

A method for determining low concentrations of lead in rocks and minerals was described by L. B. Jenkins (r0616) and Roosevelt Moore. Samples are decomposed by attack with mixed acids followed by carbonate and sulphate fusions. Lead is extracted with diethylammonium diethyldithiocarbamate and determined by atomic absorption. Lead can be determined in the parts-per-million range with a standard deviation of 2 to 3 ppm.

Lithium borate flux for K-Ar dating

J. C. Engels (r1728) and C. O. Ingamells reported on the suitability of purified vacuum-fused lithium metaborate as a flux for decomposing rock samples for determining argon and potassium for rock dating. They tested this procedure with gold, molybdenum, and tungsten crucible materials and found no adverse gaseous products to interfere with gettering materials such as titanium in the argon-extraction train or with mass spectrometric measurements. The procedure has been applied to only one sample at this time.

The microanalysis of sphene

A scheme for the microanalysis of sphene was developed by Robert Meyrowitz. The procedures include the following spectrophotometric determinations: silicon as the reduced silicomolybdate; aluminum with pyrocatechol violet; titanium with hydrogen peroxide; total iron with orthophenanthroline; and phosphorus with molybdivanadophosphoric acid.

Silver determination in geochemical exploration

A method has been developed by T. T. Chao (r1863), J. W. Ball, and H. M. Nakagawa for the determination of silver in soil, sediment, and rock samples in geochemical exploration. The sample is digested with concentrated nitric acid, and the silver extracted with an organic reagent triisooctyl thiophosphate (TOTP) in methyl isobutyl ketone (MIBK) after dilution of the acid digest to approximately 6*N*. The extraction of silver into the organic extractant is quantitative and not affected by nitric acid concentrations from 4*N* to 6*N*, or by different volumes of TOTP-MIBK. The extracted silver is stable and remains in the organic phase up to several days. The silver concentration is determined by atomic-absorption spectrophotometry.

Determination of silver at low levels in stream suspensions

T. T. Chao (r1862) and J. W. Ball developed an analytical technique using a "sampling boat" to determine nanogram levels of silver in suspended materials separated from streams by a membrane filter. Briefly, it consists of dry-ashing the membrane filter, digestion of the residue with nitric acid, quantitative extraction of silver by TOTP-MIBK, stripping of silver back into 0.3*N* HCl, and measurement of the stripped silver with the sampling-boat technique. When 2.5 liters of water are collected to determine silver in suspended materials and 0.2 ml of the final aqueous hydrochloric acid solution is pipeted for analysis, the lower limit of the method is 2 ng of silver per liter (2 parts per trillion).

NEUTRON ACTIVATION

Similarity coefficient useful for volcanic ash correlation

Large numbers of elemental abundances determined by instrumental neutron-activation analysis (INAA) are very difficult to evaluate when the number of samples is also large. Because the common methods of multivariate analysis are not applicable to certain aspects of the problem of volcanic ash correlation, and the existing equations for measuring the degree of similarity between sample analyses have serious faults; a "similarity coefficient" was devised by G. A. Borchardt, and a computer program was written to make the calculations and to classify the samples into groups. A subroutine was included in the program to eliminate redundancy among the elements. For example, eight of the 23 elements determined by INAA are rare-earth elements which geochemically are almost identical. Therefore, the 23 variables are not independent. Results obtained by this subroutine indicate that the 23 elements can be divided into approximately five geochemically independent groups. Another subroutine was written to distinguish between very similar groups of samples by using elemental ratios that maximize small differences between groups. For instance, of the 253 possible elemental ratios that can be calculated from 23 elemental concentrations, 10 were significantly more useful for classifying the Pearlette-like samples. These ratios may also help to lessen the difficulty in correlating samples altered by groundwater leaching and weathering. A commonly used factor analysis program available at the Geological Survey computer center was tested by requiring it to classify 30 analyzed volcanic ash samples. This program incorrectly classified four of the samples according to stratigraphic and mineralogical data accumulated by G. A. Izett and R. E. Wilcox. On the other hand, the classification produced with the new similarity coefficient agreed with the data of Izett and Wilcox.

Heat-producing elements in the mantle

The determination of heat-producing elements—uranium, thorium, and potassium—in ultrabasic geologic materials is important for the formulation of models of heat flow and for the characterization of samples which may have come from the mantle. Neutron-activation analysis and isotope dilution—mass spectrometric analysis have been the methods used in the past. Separate samples are used for these elements, however, and long irradiations are required for neutron-activation analysis. P. J. Aruscavage and H. T. Millard, Jr., developed a neutron-activation analysis procedure by which all three elements are measured in the same sample after a relatively short, 30-minute irradiation in a neutron flux of 2×10^{12} n cm^{-2} sec^{-1}. Carrier amounts of uranium, thorium, and potassium are added, and the irradiated sample is fused with peroxide. A series of rapid, specific radiochemical steps are performed involving extraction of the uranium, anion-exchange separation of the thorium, and precipitation of the potassium. The 23.5-min U^{239}, 22.2-min Th^{233}, and 12.5-hr K^{42} are measured in the final precipitates by low-level beta counting. Chemical yields are determined by reirradiation of these precipitates. Detection limits for this procedure are: 0.3 ppb U, 0.2 ppb Th, and 0.01 ppm K.

Preconcentration improves iodine determinations

Neutron-activation analysis has good sensitivity for iodine but, owing to the relatively short, 25-minute half life of the daughter nuclide, I^{128}, the radiochemical separations must be performed rapidly and only a few samples can be handled at one time. A. J. Bartel and H. T. Millard, Jr., found that by performing preconcentration of iodine from many samples, then irradiating these concentrates in a neutron flux and counting the I^{128} without further chemical treatment, many more samples can be analyzed in a given period of time. The chemical yield for the preconcentration steps is evaluated by spiking the samples with 57-day I^{125} and counting this nuclide in the final concentrates. The chemical steps for the preconcentration involve fusion with peroxide, dissolution of the fusion cake with sulfuric acid, reduction of IO_3^- to I^- with $SnSO_4$, oxidation of I^- to I_2 with $NaNO_2$, and extraction of the I_2 into MIBK. The reagent blank in this procedure is 0.01 μg of iodine, and the detection limit is 0.03 ppm iodine.

Collection and analysis of gold in thermal waters

A method for the collection and analysis of gold in thermal waters has been developed by J. J. Rowe and L. J. Schwarz utilizing carrier-free gold-195 as a tracer to measure the efficiency of the collection of the gold in waters onto an ion-exchange resin. The resin is dried, irradiated in the reactor, and processed through fire assay with added gold carrier. The method has been tested with laboratory samples and will be applied to field studies.

Iridium in meteorites, ores, and rocks

Two procedures for the determination of iridium in meteorites, ores, and rocks by neutron-activation analysis have been developed by L. P. Greenland, J. J. Rowe, and J. I. Dinnin. In the first procedure, applicable to samples containing 1 to 1,000 ppb of Ir, triple-coincidence counting is employed without any chemical separations. In the second method, applicable to samples containing from 0.001 to 10 ppb, fire assay is used to procure a Pt-Rh-Ir bead which is counted in double coincidence to avoid interferences from Ag^{110} and fission-produced ruthenium.

Determination of the noble metals in a single sample

In determining noble metals in geologic materials it is desirable that the same sample be used for each of the metals. Neutron-activation analysis is the only technique sufficiently sensitive to determine all the elements reliably down to background levels. H. T. Millard, Jr., and A. J. Bartel have developed a procedure by which all the noble metals, except rhodium whose half life is only 4.4 minutes, can be separated for counting within 1 day. After an 8-hour irradiation in a neutron flux of $2 \times 10^{13} n\ cm^{-2}\ sec^{-1}$, the sample is fused with peroxide along with appropriate carriers. The fusion melt is then subjected to a modified fire-assay procedure, and the noble metals are concentrated in a lead button. Following a second fusion, ruthenium and osmium are separated by distillation, and the other noble metals are isolated by anion exchange and precipitation.

X-RAY FLUORESCENCE

Rapid phosphorus determination

An X-ray fluorescence method has been developed for the determination of phosphorus over a wide concentration range in geologic materials. The method, reported by B. P. Fabbi (r1349), minimizes the problem of second-order interference by calcium K_{β_1} and K_{β_5} lines by the use of critical pulse-height discrimination coupled with a mathematical correction for spectral overlap of residual calcium.

Reduced operating voltage improves light-element determinations

G. A. Desborough and R. H. Heidel have shown that the theoretical corrections commonly applied to quantitative electron-microprobe determinations of silicon, magnesium, and aluminum in silicates and light-element oxides may be greatly reduced or eliminated by reducing operating voltages below the 15 kv which is commonly used for these elements. They point out that at an operating voltage of 6 kv, the relationship of counts to weight percentage for these elements is constant over a wide concentration range for a variety of common rock-forming silicates. Both atomic number and mass-absorption coefficient corrections are related to the nonlinear relationship of X-ray intensity to concentration for these elements at the higher operating voltages.

Minor elements in rocks

B. P. Fabbi investigated the determinations of Sc, V, Rb, Ni, Zn, As, and Sb in silicate and carbonate rocks by an X-ray fluorescence technique using pellets pressed from a 1:1 mixture of sample and cellulose. He determined that, with the use of 18 standards, and after corrections for matrix effects, quantitative results were obtained on several previously analyzed samples. The detection limit for each of the elements at a 2σ confidence limit is 4, 10, 10, 3, 6, 10, and 70 ppm, respectively.

ANALYSIS OF WATER

Atomic-absorption spectrophotometry

A very sensitive, flameless atomic-absorption spectrophotometric method for determining dissolved inorganic forms of mercury in fresh water was developed by M. J. Fishman (r1833). In the procedure, mercury is collected from an acidified sample by amalgamation on a silver wire. The wire is then electrically heated in an absorption cell placed in the light beam of an atomic-absorption spectrophotometer. The mercury vapors are drawn through the cell by a water aspirator, and the absorption plotted on a recorder. As little as 0.1 μg/l of mercury can be measured reliably by this method. Fishman also developed an atomic-absorption spectrophotometric method for determining aluminum in water at concentration levels of 100 μg/l and greater. The method involves the use of a nitrous oxide-acetylene flame which virtually eliminates chemical interference. However, with this flame, the presence of alkali metals causes a slight ionization of aluminum. To control this ionization, each standard and sample is adjusted to contain approximately 850 mg/l of sodium ion. The sensitivity of the determination is enhanced by the addition of bis(2-ethoxyethyl) ether.

Minor elements

An acid-digestion method for the solubilization of certain minor elements, particularly the group known as heavy metals, present in unfiltered or whole-water samples has been investigated by D. E. Erdmann. The whole-water sample is acidified with a small amount of nitric acid before a uniform aliquot is quantitatively transferred from the sample bottle to a beaker. This aliquot is further acidified with hydrochloric acid, heated for 30 minutes at approximately 90°C, filtered, cooled, and finally diluted to volume. The filtrate so obtained can be used to determine iron, manganese, strontium, zinc, copper, lead, cadmium, and certain other minor elements, by the methods ordinarily used to analyze filtered or settled samples. Such treatment permits the determination and reporting of the total amount of materials present in the sample and which are solubilized by the acid-digestion treatment, including those metallic cations commonly sorbed by suspended particulate matter.

A brief study was made by V. C. Kennedy, E. A. Clarke, and G. W. Zellwager to determine the losses of several trace metals that may occur during filtration of water samples through commercial membrane filters. Aliquots of tapwater and ocean water were prefiltered through 0.1-μm membrane filters, a radioisotope was added, the pH was adjusted to 6 in one aliquot and to 8 in another, and the tagged solutions were then individually forced under pressure through various 47-mm-diameter membrane filters at a rate of about 50 ml per minute. Elements studied were Ag, Ba, Bi, Co, Cs, Mn, Pb, Rb, and Zn. Filters used were Millipore HA (cellulose ester), 0.45 μm; Gelman 6A-6 (triacetate metricel), 0.45 μm; Gelman GA-9 (triacetate metricel), 0.10 μm; and Gelman VM-6 (vinyl metricel), 0.45 μm. Metal contents were in the range of 1 to 5 μg/l for Ba, Rb, and Zn; 0.1 to 1 μg/l for Cs, Mn, and Pb; and 0.01 to 0.1 μg/l for Ag, Bi, and Co.

In general, there was less sorption from ocean water than from tapwater, less sorption at pH 6 than at pH 8, and definite sorption differences between filters. The metal loss was less than 2 percent for all types of filters for Cs, Rb, Zn, Co, and Mn. About 3 percent Ba was removed by the Gelman VM-6 filter; otherwise, all filters removed less than 2 percent Ba. More than 40 percent Ag was removed from tap water at pH 8 by the VM-6 filter, but less than 1 percent from ocean water at pH 6 and 8. VM-6 filters removed 25 to 30 percent of the Pb present in tap water, but only 1 to 4 percent of that in ocean water. Other filter types commonly removed 1 percent, or less, of Pb. Bi removed from tapwater and ocean water by VM-6 filters ranged from 10 to 25 percent of that present; but for other filters the removal was on the order of 1 percent. It appears that the VM-6 filters have appreciably greater sorption capability for certain trace metals than do the GA and HA filters. Errors introduced by sorption on the GA and HA filters are relatively small compared to those that could occur during other steps in sample processing.

Automated analyses

An automated method for determining total Kjeldahl nitrogen has been developed by D. E. Erdmann; the Technicon AutoAnalyzer is used for the determination. The digestive solution consists of a mercuric oxide catalyst and potassium sulfate dissolved in a sulfuric acid solution. After digesting the sample at 340°C, the resultant ammonium ion is determined colorimetrically by the indophenol method. Total Kjeldahl nitrogen may be determined in the ranges of from 0 to 2 mg/l and from 0 to 10 mg/l, at rates of up to 15 samples per hour.

Organic substances

An electrophoresis fractionation of the dissolved organic substances present in stream waters was accomplished by J. A. Leenheer. The organic materials were first concentrated by freeze-drying, and the resulting 0.2-percent aqueous solutions then subjected to separation by electrophoresis on the basis of mass-to-charge ratios. The resulting fractions were monitored for dissolved organic carbon. By use of 0.1*M* phosphoric acid buffer of pH 2, the materials were separated into two distinct groups, one a colorless component with very little charge, the other a highly colored component of negative charge.

In previous studies, D. F. Goerlitz and L. M. Law developed methods for the determination of chlorinated hydrocarbon pesticides in soils. The procedures have now been extended to the analysis of bottom muds from streams, lakes, and estuaries. Specialized methods have been developed for the analysis of such samples, including techniques for the removal of interfering coextractives isolated with the pesticide compounds. They also found that bottom-mud samples taken from the anaerobic zone contain organic sulfur compounds that interfere with pesticide determinations. However, mixing a small drop of mercury with the bottom-mud extract greatly reduces the problems caused by these compounds.

Neutron-activation analysis

A method for the determination of mercury by neutron-activation analysis was developed by L. L. Thatcher and J. O.

Johnson. The method has been used to analyze natural and polluted water, sediments, and evaporites. Mercury bound in complex aquatic organic materials can be determined. The method involves activating the sample in a TRIGA (Training, Research, Investigations, Gulf Atomic) reactor followed by treatment with nitric and hydrofluoric acids and ammonium persulfate to solubilize the mercury and to decompose any organic complexes. The mercuric ion is then precipitated with a carrier and the Hg-197 isotope counted. A lithium-drifted germanium detector and counter array has been optimized for this purpose.

M. C. Goldberg (r0438), C. W. Gottschall, and V. J. Janzer conducted a feasibility study to determine if neutron-activation analysis could be used as a qualitative tool to characterize ground waters. Two samples from a single aquifer and four reference samples were examined. The reference samples contained major and minor elements commonly found in ground water. Twelve elements were identified in the reference samples and eight elements in the ground-water samples. No definitive comparisons resulted.

GEOLOGY AND HYDROLOGY APPLIED TO ENGINEERING AND THE PUBLIC WELFARE

EARTHQUAKE STUDIES

GEOPHYSICAL STUDIES

Microearthquake studies

A major research effort is directed toward a precise study of the distribution in space and time of earthquakes at selected localities. At present the outputs from 160 remote seismograph stations are recorded continuously in the U.S. Geological Survey Menlo Park office by telemetry. About half these stations are in California (80 along the San Andreas fault in central California and 8 more in the Santa Barbara area), and the remainder are in areas of special interest in Colorado (23 stations), Nevada (26 stations), Washington (16 stations), and Texas (7 stations). In addition, 5 permanent and 17 temporary stations in the Los Angeles area, 7 stations in Montana, and 9 stations in Alabama are recorded locally.

The earthquake activity recorded in central California in 1970 is similar to that in the preceding year. About 3,000 shocks were located, of which the vast majority lie along the San Andreas, Calaveras, Sargent, and Hayward faults. The largest earthquake in central California last year was a magnitude 5 event offshore in Monterey Bay. An unusual sequence of several thousand small earthquakes occurred near Danville (40 km east of San Francisco) during May and June of 1970. The largest events in that sequence were about magnitude 4.3. W. H. K. Lee (r1223) and M. S. Eaton found that the hypocenters of 400 of the larger events (local magnitude > 1) were located within a sphere about 2 km in diameter at a depth of 6 km.

S. W. Stewart, W. H. K. Lee and J. P. Eaton,[149] assisted by J. H. Healy, have devised an automatic earthquake-detection routine that operates in real time. The telemetered seismograph output is fed directly into a CDC 1700 digital computer which continuously monitors the seismic channels and picks the first arrivals, maximum amplitudes, and coda lengths of the events detected on the various channels. The routine is being tested on a real-time basis for the Rangely, Colo., network.

[149]Stewart, S. W., Lee, W. H. K., and Eaton, J. P., 1970, Real-time detection of local seismic events by digital computer [abs.]: Geol. Soc. America Abs. with Programs, v. 2, no. 2, p. 149–150.

San Fernando earthquake

Installation of 19 portable seismograph stations was underway on February 10, 1971, the day after the San Fernando earthquake. A preliminary analysis by R. L. Wesson (r1498), W. H. K. Lee, and J. F. Gibbs of 40 hr of recording by those stations showed that the epicenters of the aftershocks outlined an inverted U open to the south along the line of tectonic rupture associated with the earthquake. The depth of the aftershocks ranged from near surface to 15 km, with a well-defined trend of increasing depth toward the north. The overall pattern suggests that the hypocenters of the aftershocks may roughly outline the fault slip surface in three dimensions. Focal mechanism solutions for aftershocks were generally consistent with left-lateral thrust, although some evidence of normal and strike-slip faulting was found near the margins of activity.

An extensive program of remeasurement of geodetic networks within the earthquake-damaged area was also started on February 10. The preliminary results have been described by R. O. Burford (r1500), R. O. Castle, J. P. Church, W. T. Kinoshita, S. H. Kirby, R. T. Ruthven, and J. C. Savage.

The overall data are consistent with an elastic-rebound model of faulting. The maximum relative changes associated with the earthquake, as measured in Lopez Canyon east of San Fernando, were about 2 m in elevation and 2 m in horizontal distance. A simple model of faulting which accounts for most of the geodetic observations and is consistent with the aftershock distribution is reverse oblique slip on a fault plane dipping about 45° N. The dimensions of the fault plane appear to be about 15 km east-west and 20 km downdip. The average slip on the fault appears to be about 2 m reverse and 2 m left lateral. The model fault intersects the surface near the line of tectonic rupture. Repeated measurements across the line of tectonic rupture indicated no significant slip occurred there after the earthquake. However, changes of several centimeters in line lengths of a few kilometers as measured by a precise electro-optical distance-measuring device indicated continued deformation behind the line of tectonic rupture for periods of 10 to 20 days after the main shock.

R. E. Warrick (r1501) and W. B. Joyner installed six sensitive accelographs in the San Fernando Valley on February 10. These strong-motion instruments were emplaced on a variety of geologic formations to study the effect of siting upon the ground acceleration produced by aftershocks. In their preliminary analysis of the data, Warrick and Joyner found significant differences between recording sites, particularly between sites located on bedrock and on alluvium.

Earthquake prediction and modification

The search for evidence of accelerating ground tilt preceding an earthquake has been expanded by adding two new two-component tilt observatories in southern Santa Clara Valley near a region of relatively high seismicity. Present observations indicate that a noticeable change in the trend of the tilt may accompany local earthquakes of magnitude 4 and larger, but as yet no conclusive observations of premonitory tilt have been obtained. Several suggestive tilt anomalies have been observed before small earthquakes. In particular, M. D. Wood and R. V. Allen observed an anomalously large steady secular drift (0.01 μrad/day) in tilt at both Berkeley and San Francisco for 18 days preceding the main shocks of the Danville earthquake sequence (epicenter about 30 km distant). This anomalous drift terminated at about the time of the shocks.

Earthquake modification experiments are being continued at Rangely, Colo. The first real test of the procedure was begun at the end of 1970 when the pressure in several of the injection wells was reduced by backflow. As reported by C. B. Raleigh (r1189), J. H. Healy, J. D. Bredehoeft, and J. P. Bohn, the seismic activity in the vicinity of these wells was reduced substantially. Of course, because of the natural variability in seismicity, the correlation between reduction in fluid pressure and reduced seismicity must be proven by several more pump and backflow cycles. The preliminary results, however, are regarded as very encouraging.

Laboratory studies

J. D. Byerlee (r1193) has shown that motion along a fault in Weber sandstone, the reservoir rock in the seismically active Rangely oil field, takes place by stable sliding more often than by stick-slip (Byerlee, r0471). This result suggests that fault creep may be an important accommodation mechanism at the Rangely oil field. In similar experiments, W. F. Brace (r2502) (Massachusetts Institute of Technology) and Byerlee found that at temperatures above about 400°C the preferred mode of fault slip in samples of granite and gabbro was stable sliding rather than stick-slip. Inasmuch as the 400°C isotherm lies at a depth of about 15 km along the San Andreas fault, Brace and Byerlee suggest that the absence of earthquakes below 15 km is probably explained by stress release through stable sliding at those depths.

Laboratory experiments by Byerlee and Brace[150] also show that sliding on fault surfaces in gabbro is stable at an effective confining pressure below 1.6 kb but unstable above this pressure. These results suggest that anomalously high pore pressures may account for the stable creeping type of motion exhibited by some faults in the earth.

C. B. Raleigh and S. H. Kirby have examined the processes of deformation in orthoenstatite as a function of strain rate and temperature. An extrapolation of their experimental results to geologically reasonable strain rates suggest that deformation in orthoenstatite occurs by slip above about 500°C and by transformation to clinoenstatite below that temperature.

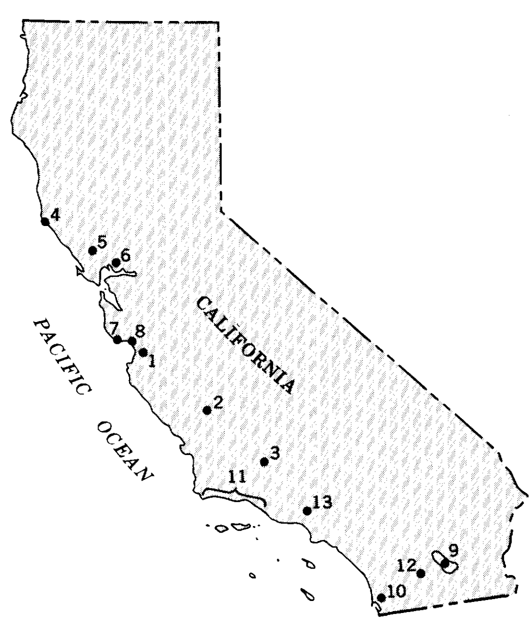
[150] Byerlee, J. D., and Brace, W. F., 1970, Modification of sliding characteristics by fluid injection and its significance for earthquake prevention [abs.]: EOS, v. 51, p. 423.

GEOLOGIC STUDIES

SAN FERNANDO, CALIF., EARTHQUAKE OF FEBRUARY 9, 1971

The U.S. Geological Survey started a multidiscipline study of the San Fernando earthquake, Richter magnitude (M) 6.6, a few hours after the main shock. Preliminary results of this study as well as those of engineers and scientists of other government, educational, and private organizations are given in U.S. Geological Survey Professional Paper 733, in 55 papers by more than 75 authors (U.S. Geol. Survey, r1494).

The epicenter was located about 38 km north-northwest of Los Angeles in the northwesternmost San Gabriel Mountains of the western Transverse Ranges of southern California (loc. 13, index map). The epicenter was about 25 km southwest of the San Andreas fault and about 3 km northeast of the San Gabriel fault, a northwest-trending right-lateral fault of the San Andreas system. The focal depth of the main shock was about 13 km. Tectonic ruptures associated with the earthquake formed along a N. 75° W.-trending zone about 10 km south of the San Gabriel fault. These data, combined with focal mechanism solutions and aftershock models indicate that



the fault surface trends about N. 75° W., dips from 40° to 60° N. toward the focus of the main shock and passes beneath the San Gabriel fault.

The prominent east-west trends and topographic relief of the western Transverse Ranges contrast sharply with the northwest trends of the Coast Ranges to the northwest and the Peninsular Ranges–Los Angeles basin–offshore borderland to the south and southeast. Although the western Transverse Ranges had been characterized by only low to moderate seismicity[151] they have long been recognized as an area of intense north-south compression. Such compression has formed the San Gabriel and Santa Monica Mountains by relative uplift along the east-trending system of reverse faults that forms their southern boundary, immediately north of the Los Angeles basin. The western Transverse Ranges appear to be caught in a vice between the easterly trending "great bend" of the San Andreas fault on the north and the Peninsular Ranges–Los Angeles basin crustal block on the south. As the latter drifts relatively northwestward during growth of the Gulf of California by lateral spreading, the western Transverse Ranges are compressed against the bend of the San Andreas.

The zone of tectonic ruptures that formed during the earthquake is about 15 km long. The western part of the zone traverses an alluviated valley in the urban areas of San Fernando and Sylmar; the eastern 8 to 9 km closely follows the east-trending base of a range of foothills that consist of steeply north-dipping upper Miocene and younger strata. Throughout the zone individual ruptures generally dip northward and have combined reverse dip and left-lateral strike slip. The expression of the ruptures varies according to the character of the surface. In the urban areas the zone is as wide as 200 m and consists of numerous subparallel small-scale ruptures; in this west part of the zone most of the displacement and compression are concentrated along its south margin, whereas extensional features make up the northern part. In natural ground the rupture zone ranges from a single, sharp scarp in consolidated rock to a broad, rounded ramp 1 to 2 m wide and 1 m high in dry stream gravels. Displacement components also vary along the length of the zone. Maximum components measured across the fault zone in San Fernando are 1.5 m reverse dip slip, 1.9 m left-lateral strike slip, and about 0.6 m horizontal shortening normal to the zone. Vertical uplift across the zone is about 1.4 m, up on the north. Larger values of vertical displacement were recorded east of San Fernando.

The zone of tectonic ruptures followed preexisting discontinuities: a previously mapped ground-water barrier and an inconspicuous south-facing topographic scarp in the alluviated valley area that underlies the western part; the eastern part follows the base of the foothills east of San Fernando. Although the ground-water barrier is coincident with the upturned south limb of a buried east-trending syncline and with a buried bedrock contact between pebbly sandstone on the north and siltstone on the south, it is inferred to be a reverse fault because alluvial cover is relatively thin north of the barrier, and it cuts across several hundred feet of section from east to west.

Several short, isolated east-trending zones of tectonic ruptures also occurred in the body of the foothills east of San Fernando and included one about 1.5 km long on the south slope of the hills where Miocene siltstone had previously been thrust over Quaternary stream-terrace deposits. An east-trending zone of ruptures about 300 m long also occurred in the foothills of the main mountain front due north of San Fernando; at this locality upper Cenozoic nonmarine pebbly sandstone had previously been thrust over Quaternary stream-terrace deposits. The main mountain front in this area generally parallels the east-trending Santa Susana thrust, a gently north-dipping fault zone along which pre-Tertiary crystalline basement has been thrust over Cenozoic units. Preliminary search has not identified any renewed movement along exposed parts of the thrust, but an inferred buried segment, the Olive View fault, may underlie part of a band of relatively intense structural damage that trends along these foothills.

The most intense structural damage associated with the earthquake occurred chiefly in two bands: a narrow one restricted to the zone of tectonic ruptures in the San Fernando area, and a broader one that trends about N. 80° E. along the foothills north of San Fernando Valley. The foothill band extends for about 10 km from the west edge of the valley to its northeast corner, about 1.5 km southwest of Pacoima dam. It was at Pacoima dam that surprisingly large accelerations were measured: 12 seconds of strong motion included two high-frequency peaks to 1 g horizontal, and vertical accelerations to 0.75 g. The severe damage in this band was due to combinations of differential ground movement associated with both faulting and landsliding, to strong inertial forces due to great acceleration of the earth, and to shaking.

Possible premonitory effects include reports by residents along the rupture zone that walls and pavement began to crack several weeks before the earthquake. Premonitory tilting of the Van Norman reservoir, 2 km west of San Fernando, may have been recorded several days before the earthquake by a marked discontinuity in the plot of metered inflow-outflow against reservoir volume based on water level.

The tectonic rupturing associated with the San Fernando earthquake was the first such event during historic time in the western Transverse Ranges; its rate, therefore, cannot be compared directly with the geologic record. The type of movement, however, was similar to that inferred to have formed the south scarp of the San Gabriel Mountains.

Probably the most significant lesson of the earthquake is its clear demonstration that the historic seismic record was an inadequate index to tectonic activity of faults in this geologi-

[151] Allen, C. R., St. Amand, P., Richter, C. F., and Nordquist, J. M., 1965, Relationship between seismicity and geologic structure in the southern California region: Seismol. Soc. America Bull., v. 55, no. 4, p. 753–797.

cally young province; it was therefore a poor basis for seismic design of high-risk structures. More reliable criteria of geological activity include identification of ground-water and topographic anomalies attributable to recent faulting, especially if these relate closely to the dominant regional pattern.

SAN ANDREAS FAULT SYSTEM, CALIFORNIA

The program of geologic investigations of the San Andreas fault system, started in 1966, continues to yield data on the total amount of displacement and on recognition and activity of faults within the system.

Cumulative lateral movement

In a continuing study of basement rocks as they relate to the lateral movement along the San Andreas fault, D. C. Ross (r0544) found distinctive gabbro on both sides of the fault but at widely spaced localities. Potassium-argon determinations on hornblende from hornblende quartz gabbro at Logan (loc. 1), Gold Hill (loc. 2), and the San Emigdio Mountains (loc. 3), and from a gabbro clast in a Cretaceous conglomerate near Gualala (loc. 4) all give Late Jurassic radiometric ages in the general range of 140 to 150 m.y. All four localities are thought to be relics of oceanic crust, on the basis of petrography, chemistry, and similarity to other ophiolitic oceanic crust occurrences. These potassium-argon ages, markedly older than those of the granitic basement of the region (generally from 70 to 90 m.y.), help confirm the exotic nature of these gabbro occurrences, which may owe their present distribution to stringing out along approximately 200 mi of the San Andreas fault.

San Francisco Bay region

Evidence that the Rodgers Creek fault in Sonoma County, Calif., has been active repeatedly in recent geologic time was obtained from geologic photoreconnaissance and fieldwork by R. D. Brown, Jr. Such features as sag depressions, scarps, trenches, and offset streams mark this complex zone of faulting, and from San Pablo Bay north nearly to Santa Rosa (loc. 5) the fault trace topography is almost as fresh and unmodified by erosion and deposition as that along the San Andreas fault, which is parallel to and about 20 mi southwest of the Rodgers Creek fault.

The Rodgers Creek fault appears to extend northward into the Healdsburg fault, which it joins near Santa Rosa. The Healdsburg fault segment of this trend also exhibits evidence of young fault movements, but north of Santa Rosa such evidence is generally less clear cut, suggesting that either the amount of movement or the recurrence rates decrease northward. Despite the relative paucity of evidence for recent surface faulting from Santa Rosa north, there is good reason to believe that this part of the Healdsburg–Rodgers Creek fault is also active. Instrumentally located earthquake epicenters[152] group along the mapped trend of the Healdsburg–Rogers Creek lineament near Santa Rosa, and an anomalous tortuous meander in the Russian River at Fitch Mountain near Healdsburg coincides locally with the fault trace and evidently records a long history of right-lateral offset in the course of the Russian River.

No evidence of historic surface fault displacement or of tectonic creep has yet been found along the Rodgers Creek or Healdsburg faults.

The comparable character of faultline features on the Healdsburg–Rodgers Creek fault to those on the historically active Hayward fault farther south across San Pablo Bay suggest that these two fault trends are continuous. Available geophysical data concerning structural trends beneath San Pablo Bay support this interpretation which conflicts with published maps that show the Hayward fault as continuing north into the Tolay fault zone.

The Green Valley fault in Solano and Napa Counties, Calif., (loc. 6) exhibits a variety of small topographic anomalies that are suggestive of geologically young fault movements. These features were first noted by R. D. Brown, Jr., in an analysis of 1:80,000-scale aerial photographs for the San Francisco Bay Region Environmental and Resources Planning Study. Such topographic features as scarps, stream offsets, trenches, and sag depressions mark the course of the fault for nearly 25 mi from Suisun Bay to Wooden Valley.

The Green Valley fault lies along the same trend as the known active trace of the Calaveras fault south of Sunol. Although on published maps the Calaveras fault is commonly curved westward into the Franklin fault, it seems likely that the zone of current fault movements continues northward without deflection and that the Calaveras and Green Valley faults are segments of a single active zone. This interpretation is based chiefly on similar surface expression of the two faults, but the aeromagnetic data of Zietz and others[153] show a number of trends that coincide with the Calaveras–Green Valley lineament.

The Green Valley and Healdsburg-Rodgers Creek faults as well as the San Andreas, Hayward, and other faults are shown on a 1:250,000-scale map of the San Francisco Bay Region, prepared by R. D. Brown, Jr. (r0398).

Santa Cruz Mountains

The zone of probable future surface rupture along the San Andreas fault is shown for the first time on a map of the central Santa Cruz Mountains compiled by E. E. Brabb

[152]Unger, J. D., and Eaton, J. P., 1970, Aftershocks of the October 1, 1969, Santa Rosa, California earthquakes [abs.]: Geol. Soc. America Abs. with Programs, v. 2, no. 2, p. 155.

[153]Zietz, Isidore, Bateman, P. C., Case, J. E., Crittenden, M. D., Jr., Griscom, Andrew, King, E. R., Roberts, R. J., and Lorentzen, G. R., 1969, Aeromagnetic investigation of crustal structure for a strip across the western U.S.: Geol. Soc. America Bull., v. 80, no. 9, p. 1703–1714.

(r0276). The fault zone was delineated by R. E. Wallace and E. H. Pampeyan from an airphoto study of such fault features as sag ponds, trenches, linear scarps, and shutter ridges. The zone of probable rupture is of considerable concern to urban planners, and similar U.S. Geological Survey maps of the Hayward fault zone already have legal status in a grading ordinance.

The Zayante fault, one of the major structural elements in the central Santa Cruz Mountains, Calif., has been extended southeastward beneath alluvium into the Vargeles and San Andreas fault systems, in a geologic and gravity study by J. C. Clark (r0102). Additional gravity data were supplied by J. D. Rietman (University of California at Santa Barbara) and the California Division of Mines and Geology. The Zayante fault is subparallel to and 4 to 8 mi southwest of the San Andreas fault for more than 20 mi northwest of the town of Corralitos (loc. 8). It has now been extended more than 15 mi southeastward into the Vergeles fault, which joins the San Andreas fault about 4 mi southeast of San Juan Bautista. The Zayante-Vergeles fault began to move during the Oligocene, and it apparently controlled and promoted the deposition of continental sediments during this period. Later vertical movements occurred locally, but they ceased by early Miocene. Since then, lateral movement along the San Andreas fault system has avoided the Zayante-Vergeles fault.

Geologic mapping by J. C. Clark (r0010), done as part of a regional study of the San Andreas fault system, has unexpectedly provided the tectonic framework for analyzing fault hazards at a proposed nuclear reactor site along the Pacific Ocean shore north of Davenport, Calif. (loc. 7). The San Gregorio fault, recognized as a major fault in the Coast Ranges of San Mateo County, projects southeastward on the sea floor towards the proposed site, and several minor faults within a few miles of the site have displaced marine terrace deposits of possible Sangamon Interglaciation age, indicating youthful tectonic activity and the possible hazards of shaking and surface displacement in that area.

SAN ANDREAS–SAN JACINTO FAULT SYSTEMS, IMPERIAL VALLEY, CALIF.

Structural details in the zone between the San Andreas and San Jacinto fault systems were obtained by a seismic reflection investigation of the sediments beneath the Salton Sea (loc. 9) by R. V. Sharp (USGS) and D. R. Sigurdson (r1099) and Tsvi Meidav (both of University of California at Riverside). The investigation revealed that folds and faults trending northwest, parallel to the San Andreas–San Jacinto faults systems, are abundant in the southern part of the Salton Sea. Distinct reflecting horizons were offset several hundred feet vertically along steeply dipping faults, some of which may have been active recently. A major synclinal axis lies subparallel and immediately west of the San Andreas fault zone near the northeastern shore. Steplike monoclinal folds, successively lower eastward toward the synclinal axis, probably mark the presence of deeper faults. The northwest-trending structures are disrupted by a transverse discontinuity located south of the central part of the Salton Sea.

Evidence of rates and locations of late Holocene fault movements along the Coyote Creek fault of the San Jacinto fault system was obtained by M. M. Clark (r1081) and Arthur Grantz in a study of scarps and trenches in lakebeds. The beds were deposited in Holocene Lake Cahuilla, which apparently persisted in the Salton Trough until about 300 years ago, and were offset by the Coyote Creek fault during the Borrego Mountain earthquake (magnitude 6.4) of April 8, 1968, and by earlier movements.

A prominent scarp (loc. 12) on the main trace of the 1968 break southeast of Ocotillo Badlands records several episodes of movement since Lake Cahuilla disappeared about 300 years ago, whereas a branch of the fault less than 50 m from this scarp sustained slip in 1968 at a location that had not been displaced for at least 1,650 years. A trench excavated across another fracture showed that vertical deformation in the past and in 1968 comprised roughly equal amounts of offset at the fracture and permanent bending of strata within a zone about 4 m wide centered on the fracture. Thus, measurements of fault offset alone may underestimate total displacement across a fault by as much as a factor of 2. The trench also revealed progressively greater vertical offset of deeper strata, from 0.56 m for the youngest to 1.7 m for the oldest.

Carbon-14 dates of mollusk shells contained in these strata yield mutually compatible vertical deformation rates of 5×10^{-4} m/yr across the break zone during the last 3,000 years and 2.5×10^{-4} m/yr across the fracture itself during the last 1,200 years. When combined with estimates of vertical offset and total vertical deformation at this location in 1968, these rates yield a recurrence interval for 1968-type earthquakes of 80 to 300 years.

QUATERNARY FAULTING IN COASTAL SOUTHERN CALIFORNIA

A broad, north-northwest-trending zone containing scattered faults which displace Pleistocene strata in the San Diego area (loc. 10) was recognized by J. I. Ziony during compilation of an environmental geologic map of the southern California coastal region. The zone occurs south of Del Mar and extends as much as 8 mi inland. The principal fracture, the well-known Rose Canyon fault with an exposed length of 5 miles, displaces the Lindavista Formation as used by Milow and Ennis[154] of late Pleistocene age and may offset the upper Pleistocene Bay Point Formation of Hertlein and Grant[155] near La Jolla; sediments approximately 13,000 yr old apparently overlap the fault at the head of La Jolla submarine canyon. Other

[154] Milow, E. D., and Ennis, D. B., 1961, Guide to geologic field trip [No. 2] of southwestern San Diego County, *in* Guidebook for field trips, Geol. Soc. America, Cordilleran Sec., 57th Ann. Mtg., San Diego, 1961: San Diego, Calif., San Diego State Coll., Geology Dept., p. 23–43.

[155] Hertlein, L. G., and Grant, U. S., IV, 1939, Geology and oil possibilities of southwestern San Diego County [Calif.]: California Jour. Mines and Geology, v. 35, no. 1, p. 57–78.

post-Lindavista pre-Holocene faults with much shorter lengths and of varied strike were identified adjacent to Mission and Soledad Valleys, on Point Loma, and in National City and Chula Vista. Numerous north- and northwest-striking faults which offset the Lindavista Formation were mapped near the Mexican border between the coast and Otay Mesa. Other faults with Quaternary displacements probably occur beneath San Diego Bay and the adjacent alluviated area. The Rose Canyon fault presumably extends along the east side of the bay and may join in the subsurface with the young faults exposed near the Mexican border west of Tijuana; alternatively, it may continue southeastward through the valley of Tia Juana River to connect with the historically active (magnitude 6.8 earthquake in 1956) San Miguel fault of Baja California.

Nearly all faults studied by Ziony along the coast between Ventura and Point Conception (loc. 11) displace upper Pleistocene deposits, and several have topographic expression suggestive of faulting or warping during Holocene time. Of particular interest is a faulted and recumbently folded Holocene(?) soil zone west of Ventura along the Red Mountain thrust, a fault which may be genetically related to the San Cayetano thrust. Brief field studies also substantiate the youthfulness of the Santa Ynez fault system. Strands of the Santa Ynez fault in Blue Canyon northeast of Santa Barbara appear to displace elevated river terrace gravels of probable late Pleistocene age. The south branch of the Santa Ynez fault offsets alluvial deposits of Pleistocene or Holocene age in an excavated trench near the mouth of Alegria Canyon about 12 mi east of Point Conception; the overlying soil zone, however, does not appear to be faulted.

THE HUASCARÁN DEBRIS AVALANCHE CAUSED BY THE PERU EARTHQUAKE OF MAY 31, 1970

The Huascarán debris avalanche associated with the May 31, 1970, Peru earthquake was a cataclysmic geological event heretofore not observed as an earthquake-produced phenomenon. G. E. Ericksen (r0144), George Plafker (r2517), and J. F. Concha (consulting geologist, Lima, Peru) investigated the area affected by the earthquake and characterized the debris avalanche as being the most destructive and geologically fascinating aspect of the earthquake. The main part of the debris avalanche appears to have involved a slab of ice and rock about 800 m wide that broke away from the shear west face of the glacier-covered north peak of Nevados Huascarán, at an estimated altitude between 5,500 and 6,500 m. The original slide mass probably involved a volume of ice and rock that was considerably greater than 25 million m^3. The amount of rock was probably much greater than the amount of ice. As the avalanche moved down the side of Nevados Huascarán and down the Llanganuco Valley, it took on the character of a highly fluid mudflow. Water was furnished by melting of incorporated ice and snow (as a result of friction and other energy release in the rapidly moving mass) and from streams and water-saturated sediments in Llanganuco Valley.

According to eyewitnesses, the avalanche from Nevados Huascarán was triggered during the earthquake. It moved downslope at high velocity with a deafening noise and was everywhere accompanied or preceded by a strong turbulent airblast. Accounts of survivors suggest that the debris avalanche traveled the 14.5 km distance from its source to the vicinity of the cemetery at Yungay in 2 to 4 minutes—an average velocity of between 217 and 435 km per hour. A velocity on the order of 400 km per hour is indicated near the middle part of the course by the trajectories of thousands of boulders, many weighing as much as 3 tons, that in some places were hurled more than 700 m across the Llanganuco Valley. This deadly rain of rocks killed and injured many people and was extremely destructive to buildings, livestock, and vegetation. The unusually high velocity and large volume of the debris avalanche allowed it to override large topographic irregularities including a 230-m-high ridge between the Llanganuco Valley and Yungay.

The avalanche's velocity was due primarily to the combination of steep slopes (as much as 70°) in the source area and to the great vertical relief (3,700 m) along its 16-km path to the Río Santa. In the upper half of its course the vertical drop is almost 3,000 m at an average slope of 23°; in the lower half the drop is only 700 m and the slope averages 5°. Frictional resistance to sliding of the mass may have been significantly reduced by admixture of snow and ice and locally, perhaps, by entrained air beneath the debris. Air-cushioned flow near the source is suggested by the fact that the debris avalanche apparently moved across ridges of unconsolidated morainal material without disrupting them.

The debris avalanche killed an estimated 20,000 people and devastated an area of several tens of square kilometers. The main part of the debris avalanche, which was channeled along the Llanganuco Valley, buried most of Ranrahirca as well as parts or all of several smaller villages along the fertile valleys of the Río Llanganuco and Río Santa. Yungay was oblitered by a relatively small tongue of mud and rock several meters thick that swept over the ridge between Yungay and the main stream of the avalanche which followed the Llanganuco Valley to the south. Only the tops of a few palm trees in the central plaza and part of the main cathedral now protrude above the mud to mark the site of this formerly prosperous and picturesque city.

WORLDWIDE CORRELATION OF SURFACE DISPLACEMENT AND RICHTER MAGNITUDE

A review by M. G. Bonilla (r1425) and J. M. Buchanan of literature on surface faulting within historic time has revealed a good correlation throughout the world between maximum surface displacements and Richter magnitudes of the associated earthquakes. Although a poor correlation exists betweem Richter magnitude and the length of surface rupture, strike-slip faults generally show a better correlation between magnitude and both length of rupture and amount of displacement than do other types of faults. This topical research was sponsored by the U.S. Atomic Energy Commission because of the critical need for improved criteria for evaluating faulting hazard at potential sites for nuclear reactors and other important engineering structures.

Although a previous study by Bonilla,[156] limited to North American events, concluded that widths of strike-slip fault zones and their associated branch and secondary faults are narrower than those of other kinds of faults, the present broader study indicates that this generalization is not true for the subsidiary faults, and also probably not for the main fault. Some branch faults have extended 6 to 12 km and some secondary faults have formed 13 to 25 km (and possibly as much as 70 km) from the main strike-slip fault. With a few exceptions, displacements on subsidiary faults in North America were less than 30 percent of the maximum displacement on main faults. About a dozen subsidiary ruptures elsewhere in the world, however, showed a displacement of more than 30 percent of that on the main fault, and a few of these had even a greater displacement than that on the main fault.

ENGINEERING GEOLOGY AND URBAN STUDIES

SPECIAL ENGINEERING STUDIES

Landslides near Denver, Colo.

According to Bruce Bryant, a serious engineering problem in the Precambrian gneiss of the Indian Hills quadrangle 10 mi southwest of Denver, Colo., is caused by foliation or fracture planes which dip at angles equal to or less than the slope of the ground surface and are inclined in the same direction as the ground surface. Landslides have originated in the past at many such places and are also occurring today. For example, slides are present in the lower part of Turkey Creek Canyon where the creek has undercut foliation planes and where slope stability has also been decreased by excavations associated with highway construction. Some landslides along the mountain front nearby have moved along joints which dip downslope parallel with the contact between rocks of Precambrian and Pennsylvanian age. Large excavations in these rocks along the base of the mountain front could cause landslides.

Landslides north of the Golden Gate, Calif.

Geologic studies by Julius Schlocker have revealed abundant landslides along the Pacific Ocean shoreline in Marin County, Calif., 2 to 5 mi north of the Golden Gate. The slides are along cliffs adjacent to the beach and extend to altitudes of more than 500 feet. The material involved is a tectonic melange that covers the north half of the Point Bonita quadrangle in the form of a nearly horizontal blanket at least 1,000 feet thick. The melange consists of hard blocks of rock from a fraction of an inch to several hundred feet across in a strongly sheared silt and clay matrix. The blocks are of rock types of the Franciscan Formation, mostly graywacke and basaltic volcanic rocks, but some are radiolarian chert and blue schist. The matrix, which locally may form more than half of the melange, contains montmorillonite, chlorite, and mica, and becomes soft, plastic, and of low strength when wet. Landslides in the melange include debris slides, debris avalanches, rockfalls, earthflows, slumps, and block glides. Although some parts of the slides have moved very recently, the upper boundary of the slide areas seems to have been established long ago and only locally has advanced upslope (eastward) within the last 75 yr. Parts of the shoreline are now stable because of the presence within the melange of giant blocks of hard rock.

Landsliding is the dominant process of shoreline erosion and retreat in this sector and creates a continuing hazard to State Highway 1 and to small buildings near the shore. Existing and potential instability of slopes formed on the melange should restrict future urban development along and near the shore. Because of the wide range of rock types within short distances in the melange, construction on it should be preceded by careful site examination of its engineering properties. This precaution should also be followed within the broad area underlain by the melange between the Pacific Ocean and San Francisco Bay.

Usefulness of geologic maps in the San Francisco Bay area, California

Reconnaissance mapping of areas underlain by the Sonoma Volcanics (Pliocene) north of San Francisco Bay, Calif., by K. F. Fox, Jr., reveals that the sequence consists chiefly of andesitic lava flows, fragmental volcanic rocks, and ash-flow tuffs. The sequence is folded and faulted over much of its extent. The lithologic variability of the rocks, and their strong deformation, causes lateral changes in both bedrock and soils within short distances. Geologic maps that show these changes can be helpful in land-use planning. Successful upland vineyards, for example, are mostly limited to areas underlain by lava flows rather than volcanic tuffs.

Some unexpected uses for geologic maps have been brought out by questions from private citizens and consulting geologists after the release of a geologic map of the central Santa Cruz Mountains in the San Francisco Bay region, California, by E. E. Brabb (r0276). Most of the users were concerned with the location of active faults and landslides in connection with the purchase or development of property or school sites, but some used the map to search for sand and gravel deposits or water. One geologist from an electric power company was interested in the weathered color of the rock units because

156 Bonilla, M. G., 1967, Historic surface faulting in continental United States and adjacent parts of Mexico: U.S. Geol. Survey open-file report, 36 p.; also U.S. Atomic Energy Commission Rept. TID-24124, 36 p.

light-colored rocks reflect more heat that interferes with power transmission. The map was also used by a Federal attorney in defending a suit against the Government for alleged property damage during construction of a power line. The map indicates that the property in question is partly within a landslide that could affect its development and value.

Utilization of compression arches in coal mines in Colorado

A new insight into the distribution of anomalously high stresses in coal mines was obtained by C. R. Dunrud in the Somerset mining district, Delta and Gunnison Counties, Colo., as part of a continuing geologic study of coal-mine bumps. Analysis of rib deformation in one coalbed revealed that much of the overburden load was bridged across an area 300 feet wide and 500 feet long that coincided with a mined-out area in a higher bed, probably by an arch of compressional stresses. Mine ribs in the lower bed were severely crushed beneath the arch abutments (margins of the mined-out area), but were virtually undeformed beneath the arch span. Although overburden stresses were thus reduced directly beneath the mined-out area, they were greatly increased in arch abutments at the margins. The claystone and sandstone beds above the coalbeds are not strong enough to form a large, unsupported, composite beam across the mined-out space.

Such compression arches can be utilized in planning the safest and most efficient methods for mining a succession of coalbeds. Planning should provide for the proper spacing of mine workings so that undue abutment stress is not placed on working faces and haulageways, for adequate support of compression arch abutments, and for mining coal from the upper beds of a sequence first.

Utilizing stable compression arches in designing multiple-bed mining plans could increase minable coal by several percent. An increase of only 1 percent in minable coking-coal reserves in the Somerset district would amount to 2 million tons, with a value of $25 million.

Subsidence above coal mines in Kentucky

Undrained depressions in the Millport quadrangle, Hopkins and Muhlenburg Counties, Ky., were found by G. J. Franklin to be related to coal mines at depths of tens of feet to a few hundred feet. Evidently subsidence was caused by the extrusion of underclay from beneath pillars left in the mines. The depressions are a few feet deep and as large as 500 feet wide and 1,500 feet long. Future construction in such areas of subsidence will encounter problems of surface drainage and unstable foundations.

Studies in soil engineering and rock mechanics

The compaction of granular soils can be analyzed more effectively in terms of strains than in terms of stress changes and the accelerations and frequencies of vibrations. According to T. L. Youd (r1545), the latter approach has not led either to a clear understanding of the densification behavior of sand or to adequate methods for predicting in-place compaction from nonvibratory and vibratory rollers and from earthquakes. Youd's study shows that shear strain is more important than volumetric strain in the compaction of granular materials, that densification behavior under repeated cycles of shear strain can be explained in terms of the well-defined behavior of sand in monotonic shear, and that repeated shear strain densifies sand to a substantially greater degree than standard vibratory methods. Laboratory data on the densification behavior of sand in response to cyclic strain lead to estimates of in-place density changes from static, vibratory, and seismic sources which are consistent with published field data.

Undercoring experiments under controlled conditions of temperature and humidity were performed in the laboratory by D. J. Varnes on a sample of Wingate Sandstone from Utah. The strain changes due to undercoring a freed rock were predictably affected by temperature and humidity changes, but were generally too large to be solely the result of these factors. The excess strain changes seem to have been produced by the release of residual stress previously locked in the rock.

SAN FRANCISCO BAY REGION ENVIRONMENT AND RESOURCES PLANNING STUDY

The San Francisco Bay Region Environmental and Resources Planning Study (SFBRS), begun in January 1970, is a study of both the physical environment and the resources of the region and their significance to urban and regional development and planning. This is a 3-yr pilot study being conducted cooperatively by the U.S. Geological Survey and the U.S. Department of Housing and Urban Development. The study emphasizes the disciplines of geology, geophysics, hydrology, and topography—disciplines that are the basis of the expertise of the U.S. Geological Survey—and the pertinence and application of these disciplines to improved regional urban planning and decision making.

The San Francisco Bay region was selected for this pilot study for several compelling reasons. Few regions must contend with water assets including the Bay itself which are of such great economic, aesthetic, and climatic importance. In the Bay region are such natural hazards as earthquakes, flooding, and landslides. The region is large, has a present population of about 5 million people, and is being urbanized rapidly. The political and public attitudes in the Bay region are more receptive than in many other areas to the proposition that environmental considerations are important to the quality of life. The Association of Bay Area Governments and the Bay Conservation and Development Commission are regional agencies in existence that, among others, can channel environmental data into the planning and decision-making process.

A practical consideration is that the presence in the Bay area of one of the main centers of the U.S. Geological Survey makes it possible to carry out a study such as this at a fraction of the cost and time that would be needed in many other parts of the country. A sizable segment of the Geological Survey's on-going program in the Bay region is producing basic data pertinent to the SFBRS, and it is this segment that is being augmented so that the pilot study can be completed in 3 yr.

Some of the work summarized below also appears in more detail under other appropriate headings elsewhere in this volume, but all such work is an integral part of the SFBRS.

GEOLOGICAL AND GEOPHYSICAL STUDIES

The geological and geophysical studies of the San Francisco Bay region fall into five principal elements: (1) active faults, (2) seismicity and ground motion, (3) slope stability and engineering behavior of bedrock areas, (4) physical properties of unconsolidated deposits, and (5) mineral commodity utilization. Data on each of these elements are being developed and will be presented in a manner that will be directly applicable to land-use development, planning, and decision making in the Bay region.

Active faults

The San Francisco Bay region is traversed by three major active earthquake-generating fault zones and by several smaller active or possibly active faults. Locating and determining the anticipated activity of these faults is an important part of the study. These faults are being studied by surface and subsurface geologic techniques, distribution of microearthquakes, and measurement of crustal strain. It is hoped that from these data the location of most future disruptions of the earth's surface along active faults in the Bay region can be predicted, and an estimate of the frequency of future episodes of fault slip and destructive earthquakes can be made. Some of the preliminary results of this study are described below and in greater detail in the section on earthquake studies.

Seismicity and ground-motion studies

Seven of an eventual nine new seismograph stations have been put into operation between San Francisco and Santa Rosa, Calif., to supplement the existing central California microearthquake network. This augmentation will greatly improve the location capability for earthquakes in the northern San Francisco Bay region, and will delineate the continuation of the Hayward and Calaveras faults north of the Bay.

Analysis of data recorded by the central California microearthquake network is on a current basis. The locations of large events (magnitude 2½ or greater on the Richter scale) are determined on the day of occurrence, and the location of smaller events are determined each week.

A four-level, three-component downhole seismometer array has been in operation on the west shore of San Francisco Bay since August 1970. Techniques for digitization and spectral analysis of the array seismograms have been developed and applied to recordings from moderate-sized local earthquakes and from the San Fernando earthquake of February 9, 1971. The amplification spectrum shows significant peaks at periods of 0.5, 0.8, and 1.8 seconds. The spectrum is being compared with theoretical predictions based on available information on the geology of the recording site in an effort to develop models that can be used for predicting the characteristics of earthquake ground motion at sites around the Bay.

Progress has been made in the development of seismic field techniques for prediction of earthquake ground motion. Successful measurement of near-surface shear velocities were made at a site on the west shore of San Francisco Bay. Near the same site a seismic-reflection profile succeeded in recording a distinct and persistent reflection which corresponds to the basement surface beneath the older sediments as confirmed by subsequent drilling.

Six strong-motion accelerograph stations were established along a profile across the Santa Clara Valley near Gilroy to determine the effect of sediment thickness on earthquake ground motion. The instruments were removed temporarily to record aftershocks of the San Fernando earthquake of February 9, 1971, to provide data on the effect of local geology on ground motion.

Slope stability and engineering behavior of bedrock

The behavior of the ground as it affects engineering construction and development places varying constraints on man's use of the land, and the possibility of landslides, particularly, will become an increasingly dominant constraint as the need for housing sites extends into the hillside areas. In order to make the best and most economical use of the land, unstable slopes must be identified. To meet this need the distribution and character of existing landslides in the region are being determined by studying aerial photographs and by limited field investigations. The occurrence of the landslides will be related to the natural and artificial processes which cause them, including lithology, geologic structure, amount and height of slope, rainfall, and land-use practices. The results will be used to predict slope stability over the entire San Francisco Bay region.

Physical properties of unconsolidated deposits

Most of the population in the San Francisco Bay region is concentrated in lowland areas underlain by unconsolidated sedimentary deposits. As population increases, greater demands will be made on these areas for residential and other use. The unconsolidated deposits in lowland areas pose special problems that should be taken into consideration in the development and use of these areas. Ground-motion studies of these unconsolidated materials are being made to evaluate their behavior during earthquakes. The unconsolidated deposits are also being studied to determine their foundation characteristics such as susceptibility to liquifaction and compressibility bearing strength. Ground water from unconsolidated deposits in lowland areas forms a major source of water in many parts of the Bay area, and data on this important resource are being developed.

Mineral commodity utilization

Continued industrial growth and urbanization in the San Francisco Bay region will require the utilization of large quantities of construction mineral commodities. Many of these commodities are available within the Bay region itself. It is advantageous to utilize local resources where this can be done without degrading the environment, because proximity to markets is a large part of their intrinsic value. An inventory and evaluation of the mineral commodities of the Bay region is being made. The major deposits, districts, and areas of economic potential of major commodities will be delineated, classified, and ranked. A second phase of this work will be to determine the social and economic impact, and the environmental factors which attend the utilization or nonutilization of the various mineral deposits of the Bay region.

HYDROLOGIC STUDIES

Water-related elements in the SFBRS are being considered in two principal contexts—those concerned with water as a basic resource, and those related to water as a hazard.

The major San Francisco Bay area cities import most of their domestic and industrial water from outside the region. Many communities and a large share of agricultural users, however, depend on local ground-water supplies. Therefore, summarization of ground-water availability, water quality, and areas that offer promise for recharge of aquifers by local or imported water is of prime importance. These data are being prepared by D. A. Webster, who is also identifying specific wells that may be used for emergency water supply in the event of disaster.

S. E. Rantz (p. C237–C241) has developed a method whereby the statistical frequency of rainfall of selected intensities and durations at any place in the region can be calculated, departing from a map showing mean annual rainfall. His studies further will relate to changes in flood peaks as urbanization progresses and to criteria for design of flood-water runoff structures, departing from the completed study of rainfall intensities. The areas likely to be inundated by the so-called 100-year flood throughout the region are being mapped by J. T. Limerinos. So far, 25 quadrangles have been completed and the maps published.

Maps showing areas serviced by municipal and private water-distribution agencies and sewerage agencies have been prepared by J. T. Limerinos and Karen Van Dine for use by regional planners in the Bay area. The first map shows the boundaries of 84 service areas keyed to a tabulation of water-distribution agencies in the nine bay-area counties. Additional information on source of water, population, and consumption is being tabulated. The second map shows service-area boundaries and treatment-plant locations keyed to a tabulation of 110 sewerage-disposal agencies in the nine bay-area counties.

Physical and chemical hydrologic properties of San Francisco Bay are the concern of T. J. Conomos and D. H. Peterson, working in close coordination with D. S. McCulloch, P. R. Carlson, and other marine scientists of the Geological Survey. Preliminary reports (T. J. Conomos and others, r0062; D. S. McCulloch and others, r0061) discuss the results of some of this work. Water-quality characteristics of the south bay region are influenced primarily by inflow of fresh water, manmade water, and tidal exchanges of water of varying salinity. Change in any of these controls could have significant effect on the overall quality of the Bay. One of these reports (D. S. McCulloch and others, r0061) qualitatively demonstrates that high and low seasonal inflows of fresh water to the San Francisco Bay system through the Sacramento River delta correlate inversely with salinity and phosphate concentration in the south bay. This inverse relation suggests that net fresh-water flow to the Bay from this source is a major quality control under present conditions. The movement of seabed drifters in the Bay estuary and the adjacent Pacific Ocean is described in the section of this volume entitled "Marine and Coastal Geology" (p. A94).

The effects of waste-water effluents on receiving waters in the San Francisco Bay proper and tributary streams are the concern of W. G. Hines and R. C. Averett who are studying the historic changes in water quality of selected streams and identifying those changes that result from the activities of man. A waste-load map of the Bay combines information from many sources to show effects on each of six parts of the bay of biochemical oxygen demand, calculated to a long-term basis by a new approach, of nutrients, and of relative toxicity. Assisted by T. D. Steele, Hines has related the waste loads just mentioned to patterns of land use in areas tributary to each of the six parts of the Bay. An attempt will now be made to project what waste loads might be, and how they might vary, in response to changing patterns of land use as forecast by the Association of Bay Area Governments.

R. C. Averett is studying the "health" of lakes in the region to determine the degree of eutrophication prevailing, and to suggest management patterns by which the eutrophication processes can be delayed, possibly even reversed, in those waters. Problems of disposal of both fluid and solid wastes on the land surface also will be studied in relation to varying patterns of surface permeability, depth to ground water, and protection of ground-water resources from contamination.

The geohydrology of an area in Napa Valley is being studied by R. E. Faye to determine if additional supplies of ground water can be developed. Preliminary studies of water-level fluctuations indicate that there has been little, if any, mining of ground water in the valley. A reconnaissance indicated the existence of large areas of highly permeable material along the periphery of the valley floor and into the surrounding foothills. Silt and other fine-grained material occur throughout the flood plain and in places along the channel of the Napa River. Older alluvial deposits are cemented and appear to have little permeability near the confluence of Conn Creek and Napa River. This cementation, which may result from the activity of hot springs in the upper part of the basin, probably occurs along a considerable reach of the river. These findings suggest that significant ground-water recharge occurs through the permeable peripheral areas of the valley. A digital model will be constructed to simulate the hydrology of the valley so that the hydrologic system may be better understood.

Sediment yield in the area is being evaluated by W. M. Brown. In addition to determining sediment-transport characteristics of representative streams by sampling, Brown will attempt to determine factors that influence sediment yield. That study will integrate many factors such as slope, rock types, slope stability and erodibility of soils underlying various drainage basins, and the rainfall intensity-duration factors developed by Rantz, discussed above. This project is still in the data-collecting stage, particularly with respect to sediment studies in streams. It depends heavily on completion of geologic mapping, of slope maps, and of slope-stability studies of other work elements of the SFBRS.

TOPOGRAPHIC STUDIES

A new regional topographic map covering an area of 10,352 sq mi in three sheets at 1:125,000-scale has been completed and readied for publication. The map is especially oriented for the SFBRS to support the multitude of data that geologists, hydrologists, and planners will produce. The primary source of map information used in the compilation was the standard 7½-minute quadrangles; major features such as highways and canals were updated from aerial photography taken in 1970. The contour interval is 200 feet with supplementary 40-foot contours in the flat areas.

The sheets were finished for color reproduction with up to 26 separate color plates for each sheet. For special uses of the map as a base, selected plates with specified data may be composited, eliminating unnecessary detail.

A companion 1:125,000-scale orthophotomosaic was produced by use of specially planned photography flown in April 1970 at 40,000 feet above the terrain. The photography was flown in north-south strips with exposures over the center and edges of each 7½-minute quadrangle.

Orthophotoscopic scanning produced negatives at approximately 1:29,500 scale, each covering a 7½-minute quadrangle. The negatives were reduced to 1:125,000 scale and mosaicked into a three-sheet orthophotomosaic. A byproduct of the mosaic has been orthophoto quadrangles at 1:24,000 scale made by slightly enlarging the 1:29,500-scale negatives and including the projection lines and marginal information identifying each with the standard quadrangle. On special demand, contours from the standard quadrangles have been overprinted on the orthophoto quadrangles.

INVESTIGATIONS RELATED TO NUCLEAR ENERGY

UNDERGROUND NUCLEAR EXPLOSIONS

EXPLORATION AND RESEARCH IN THE DEVELOPMENT OF SITES

Nevada Test Site

The Nevada Test Site (NTS) in southeastern Nevada is the area within which the U.S. Atomic Energy Commission conducts most of its underground nuclear explosion tests. Since 1956 (before the first underground nuclear explosion), the U.S. Geological Survey has made extensive and detailed studies, on behalf of the Commission, of the geology and hydrology of the NTS. These studies have provided the earth-science data necessary to insure proper environmental safeguards in the underground testing of nuclear explosives. The Geological Survey participates in the appraisal of the safety, engineering feasibility, and postshot effects of all explosions conducted at the NTS.

There is an increasing need to perform rapid, accurate in situ measurements of the physical properties of testing media. Methods developed for obtaining such measurements at the NTS can be implemented at other areas of underground nuclear explosions. A method has been developed by R. D. Carroll to obtain seismic-interval velocities and electrical resistivity of rocks in horizontal drill holes to distances of 3,000 feet or more. Data are obtained in wet or dry holes by pumping a probe out of the steel casing ahead of the drill bit. Static readings are obtained during intervals when the drill string is being broken in the process of coming out of the hole.

Schmidt (impact) hammer tests have been conducted by J. R. Ege (r1367), D. R. Miller, and Walter Danilchik in drifts beneath Rainier Mesa at the NTS. These tests have demonstrated that this testing instrument, originally designed for concrete testing, provides a rapid, precise method for field determinations of elastic and physical properties of rocks. Schmidt hammer rebound values (R) on freshly exposed zeolitized tuff were compared with laboratory measurements of elastic and physical properties of natural-state samples collected and sealed shortly after mining. Comparison of R with dynamic tests of compressional velocity, shear velocity, Young's modulus, and shear modulus, and with static tests of unconfined compressive strength, secant Young's modulus, and shear modulus yielded correlation coefficients of 0.81 to 0.89. Correlation coefficients of R with dynamic and static bulk modulus, density, and porosity ranged from 0.70 to 0.79. Correlation coefficients of R with dynamic and static Poisson's ratios were -0.41 and -0.12, respectively. The use of the Schmidt hammer on dry core is under investigation.

Magnetic-susceptibility measurements on 346 drill core samples taken at 5-foot vertical intervals in the Climax and

Gold Meadows stocks at the NTS show that the susceptibility increases at an average rate of 1.15×10^{-4} gauss/Oe per 100 feet of depth in the two plutons. The data indicate to G. D. Bath that the increase in susceptibility is due to an increase in percentage of magnetite and not to decrease in porosity or decrease in weathering with depth. Aeromagnetic anomalies (about 40 sq mi each) over the plutons (exposed only over about 1 sq mi each) can be explained by the increase in susceptibility over a depth interval of several thousand feet with only a minimal increase in pluton diameter with depth. If the increase in susceptibility were not known, the inferred shapes of the plutons would have to resemble truncated cones with diameters increasing with depth in order to explain the aeromagnetic anomalies.

Central Nevada

Geologic exploration and development efforts at the central Nevada test site in Hot Creek Valley, northern Nye County, were greatly curtailed because of the decision of the U.S. Atomic Energy Commission to discontinue use of the test site. Geologic field studies by E. B. Ekren and others have been conducted intermittently in order to complete the quadrangle mapping that was begun when development of the test site was at its peak. These studies have added significantly to the understanding of the Tertiary geologic history of the area through correlations of ash-flow tuffs, recognition of cauldron boundaries, and recognition of several zones of strike-slip faulting.

Amchitka Island, Alaska

An interim summary of the results of geologic, geophysical, and hydrologic investigations in the western Aleutian Islands, Alaska, was reported recently by W. J. Carr (r1668), L. M. Gard, G. D. Bath, and D. L. Healey; it includes some of the data that would otherwise have been summarized herein. Geologic research and development of the Amchitka test site is continuing on a regular basis in preparation for planned use of the site.

Data from gamma-gamma logs of holes drilled in volcanic rock on Amchitka Island have been analyzed by D. L. Healey. The data show no systematic increase in density with depth. Also, the values are surprisingly low. For a drill hole 6,000 feet deep, the averages are 2.37 g/cm^3 for gamma-gamma density, 2.36 g/cm^3 for sample densities of drill core, and 2.36 g/cm^3 for density computed from in-hole gravity measurements.

Published and unpublished geologic and geophysical data that were reviewed by R. E. Anderson (r1109) indicate that known and inferred structures affecting the upper crust of the central Aleutians reflect predominantly tensional strain of diverse orientations, whereas evidence from natural seismicity suggests predominantly compressional strain across the Aleutian arc. Features of probable tensional origin on the Aleutian Ridge are inferred to have formed from igneous-related tectonism including distension of the surficial skin over rising and spreading epizonal plutons, volcanotectonic subsidence, and rifting. The plutonism is considered to be the result of a first-order process of crustal foreshortening across the arc. The features of tensional origin are, according to this view, second-order structures that are in most areas inactive because plutonism has ceased beneath most of the ridge. The structure of the Aleutian arc is inferred to be strongly modified where an inactive postulated Bowers Ridge arc intersects it near Amchitka. A highly speculative result of this arc-arc intersection would be a low-angle fault dipping away from the leading edge of Bowers arc beneath Amchitka which could serve as an effective zone of tectonic and seismic decoupling across Amchitka Pass.

RESEARCH ON THE EFFECTS OF NUCLEAR EXPLOSIONS

To insure the proper evaluation and selection of each individual test site in terms of the environment, research is conducted on the geologic and hydrologic effects of nuclear explosions. The results of these studies are used to determine the amount and type of earth-science information required for assuring that future tests do not exceed environmental considerations.

Geologic effects

Studies of doming and collapse phenomena, seismicity, faulting, and other explosion-induced strain features and the relationships of these to other geologic and hydrologic factors form part of the ongoing geologic effects effort of the U.S. Geological Survey. The results are of great value, for they form an empirical and quasi-theoretical basis for predicting the geologic effects of nuclear explosions and for developing an understanding of those effects.

The use of data on the tectonic effects of nuclear explosions is exemplified by the predictions of fault movement and aftershock zones made by F. A. McKeown. These predictions were made for the Handley event and were used by seismologists of the Geological Survey's National Center for Earthquake Research to install seismometers in optimum locations for accurate determinations of epicenters and hypocenters of Handley aftershocks. Similar predictions are currently being used by several organizations to locate seismometers, biological transects, survey stations, camera stations, and ocean bottom wave gauges for the Cannikin event on Amchitka Island, Alaska.

F. N. Houser has studied the sequence of events that accompany the formation of sinks over underground nuclear explosion cavities at the NTS.[157] An understanding of the dynamics of sink formation is important because the subsid-

[157]Houser, F. N., 1970, Sequence of surface movement and fracturing during sink subsidence, Nevada Test Site: U.S. Geol. Survey Rept. USGS-474-56, available only from U.S. Dept. Commerce Natl. Tech. Inf. Service, Springfield, Va., 44 p.

ence event is known to stop or severely curtail eruptions of detonation gases. Houser has determined the cause-and-effect relationships that occur during the development of the four principal zones of the sink (designated outwardly from the center as zones 1 through 4). A central, generally circular area (zone 1), which is radially slightly less than one-half the final sink radius, begins downward movement. As its surface becomes dish shaped and extended, through slight variations in starting times, tensile stress increases in the surface, and the area is radially fractured. As a consequence of movement in the central zone, inward and downward movement begins in the adjacent alluvium (zone 2), which moves virtually en masse. This zone is tilted toward zone 1 and is stressed tensionally until separated from the surrounding alluvium by concentric fractures at the zone 2–zone 3 boundary. Surface tension is soon replaced by compression at the inner boundary of zone 2 and throughout zone 1, closing the concentric and radial fractures previously opened. The release of lateral restraint at the inner edge of zone 3 causes arcuate blocks of alluvium to move inward and downward without significant tilting. This is then followed by simple concentric fracturing in zone 4 outside the topographic lip of the now well-formed sink.

A detailed study of the Handley event in Pahute Mesa, NTS, utilizing high-accuracy geodetic data, by R. C. Bucknam (r0802), D. D. Dickey, and F. A. McKeown, shows that a depressed area, centered about 400 feet east of ground zero and extending as much as a mile from ground zero, resulted from the explosion. A profile of the depressed area shows similarities to the profile of subsidence over a Gulf coast sulfur mine described by Deere.[158] The Handley event also activated faults whose displacements are consistent with the deformation predicted by the theoretical analysis of a dislocation in an elastic half-space as commonly used in earthquake deformation studies.

An analysis of aftershock distributions and their relationships to geologic structures has been made by F. A. McKeown (r1034), P. P. Orkild, and R. C. Bucknam. Aftershocks from the Handley event in Pahute Mesa and the Milrow event on Amchitka Island tend to be distributed in wedge-shaped zones bounded and broken by faults. This tendency for aftershocks to be located in wedge-shaped zones is compatible with the fact that such zones would have high stress gradients and, therefore, have less structural stability than blocks of ground between widely space parallel faults. Distribution of aftershocks from the Benham and Jorum events in Pahute Mesa coincides more closely with caldera collapse zones than with Basin and Range fault zones. On the basis of descriptions of active and ancient calderas, caldera collapse zones are likely to be comprised of landslidelike blocks that have wedge-shaped forms. If so, high stress gradients and low structural stability would be expected in those areas.

[158]Deere, D. V., 1961, Subsidence due to mining–A case history from the Gulf Coast region of Texas: Fourth Symposium on Rock Mechanics, Proc., Mineral Industries Expt. Sta. Bull. 76, Pennsylvania State Univ., p. 59–64.

An additional indication of a relationship between explosion-induced strain phenomena and caldera structures has been found by D. D. Dickey. Strains calculated from geodetic measurements made before and after the Jorum event show reasonably consistent principal strain directions over the area-20 collapse zone of the Silent Canyon caldera (three strain nets) and inconsistent principal strain directions over other structural blocks (four strain nets).

An analysis of data by F. T. Lee from borehole stress probes installed in shallow drill holes in Pahute Mesa revealed a strain decay with distance from nuclear explosion. Initial changes of stress, from several hours to several days postshot, were decompressive (relative tension). With time the rock stresses increased in compression, but the rock retained a net shot-induced decompression months after the nuclear event. Faults and joints apparently adjust for long periods after a nuclear shot. Underground stress-strain measurements before and after Diesel Train nuclear event by F. T. Lee and T. C. Nichols, Jr., from G tunnel in Rainier Mesa, NTS, also indicated a postshot decompression followed by partial compressive recovery after several weeks. Atomic explosions appear to permanently alter the stress-strain state of the rock mass.

Hydrologic effects

The U.S. Geological Survey monitors and interprets transient and long-term hydrologic effects of underground nuclear explosions. Studies of hydrologic response to explosions are made at varying distances from the explosion site. As with the geologic-effects studies, the data and results are used to predict hydrologic effects and to understand their phenomenology.

Fluid pressures in sealed wells were monitored by D. D. Gonzalez and W. W. Dudley, Jr., during and after nuclear detonations at the NTS. The data provide a basis for improving the prediction equation for the dynamic-phase overpressure, in bars, as related to distance and yield. The improved equation derived by standard multiple regression techniques is:

$$+H = 0.259\, W^{0.891} R^{-1.61} ,$$

where $+H$ = peak positive pressure in bars, W = device yield in kilotons, and R = distance from explosion in kilometers. Pressure transducers, suspended below static water level in open wells and mated to high-speed recording oscillographs, have been used to measure rates of surging in production (pumping) and nonproduction wells during the passage of seismic waves. Cyclic surging with periods of 1 to 3 sec and magnitudes as great as 100 gpm have been observed 120 km from nuclear tests of high to intermediate yield.

R. K. Blankennagel has compiled hydraulic, chemical, and radiochemical data (1957–70) from the supply wells at the NTS. The data indicate no permanent changes attributable to nuclear testing. A detailed investigation of a well field 70 mi northwest of the NTS indicates a more significant correlation of well failure with factors related to pumping and well construction at the well field than with explosion-induced transient pressure response of the wells.

S. W. West reports that data from selected streams, wells, springs, and precipitation collected in conjunction with the reentry drilling and flaring phases of Project Rulison has shown that no change from predetonation background has occurred in the region of sampling in central and western Colorado. These data are available in various reports by P. T. Voegeli, Sr. (r1541, r2117), and H. C. Claassen (r2503).

The postshot recoveries of the hydrologic regimen were found to be very different for the Faultless event in Hot Creek Valley in central Nevada and the Milrow event on Amchitka Island, Alaska. Water-level studies by G. A. Dinwiddie at the Faultless site indicate a lack of hydraulic connection between the collapse zone and the surrounding aquifers. Water levels near the detonation site, but outside the collapse zone, have returned to their predetonation values whereas those in the collapse zone are several hundred meters below predetonation values.

Immediately following the Milrow event on October 2, 1969, the discharge of Clevenger Creek, a small stream that drains the Milrow site, was reduced 50 percent. The detonation of the Milrow event formed a large cavity about 4,000 feet beneath the surface with a vertical rubble chimney above the cavity. The ground-surface expression of the event was a subsided area with a radius of about 875 feet which intercepted the surface-water flow in the upper reaches of the Clevenger Creek drainage. Studies by W. C. Ballance show that the decrease in discharge of Clevenger Creek persisted through October, November, and December 1969. On January 1, 1970, the discharge of Clevenger Creek returned to normal, indicating surface water was again flowing from the upper reaches of the drainage basin. Ballance concludes that the Milrow chimney was saturated and would accept no more water.

Intensive post-Milrow surface-water monitoring indicates that no radioactivity above background has been released to the surface waters on Amchitka or nearby oceans since the event occurred.

RELATION OF RADIOACTIVE WASTES TO THE HYDROLOGIC ENVIRONMENT

Radioactive materials in suspension or solution are discharged to the hydrologic environment as a result of the operation of a wide variety of nuclear-energy facilities. The research on this subject is sponsored by the U.S. Atomic Energy Commission and is related primarily to the transport of these materials through the hydrologic cycle. The research also is applicable to predicting the fate of radioactive materials that could be released accidentally to the hydrologic environment.

Part of the research is devoted to protecting the hydrologic environment from contaminating solutions that might be derived from disposed solid or liquid wastes, and part is related to new waste-disposal methods and techniques.

Columbia River and estuary

In studying the movement and occurrence of radionuclides derived from the U.S. Atomic Energy Commission's Hanford, Wash., reactors, the last of which was shut down early in 1971, D. W. Hubbell, J. L. Glenn, H. H. Stevens, Jr., and G. A Lutz observed a so-called turbidity maximum within the Columbia River estuary wherein the concentrations of suspended particulate matter are considerably higher than they are either landward or seaward. The magnitude and the longitudinal position of the turbidity maximum vary throughout the tidal cycle; generally, the feature is associated with the position of the front of the salt-water intrusion along the bottom of the estuary. The turbidity maximum abates during slack water and redevelops with each ebb and flood tide because of the resuspension of fine material that tends to accumulate as a result of the estuarine circulation pattern. The existence of the turbidity maximum influences the transport of radionuclides and, at times, causes a net upstream discharge of radionuclides associated with particulate matter.

Interpretations by J. L. Glenn, H. H. Stevens, Jr., and D. W. Hubbell of acoustic records from a subbottom seismic-profiling and side-scan sonar survey undertaken in September 1968, when the upland flow was about 120,000 cfs, have revealed that a significant portion of the bed in the upper estuary is exposed bedrock; hence, the potential for the storage of radionuclides in the bed is less than had been assumed previously. Also, in the lower estuary, sediment movement, together with its associated radionuclides, was landward along the bottom in deep channels up to about mile 14 on the Columbia River, but was seaward on slopes and flats marginal to the channels downstream to about mile 5 on the river.

G. A. Lutz has found that use of a variable roughness factor throughout the tidal cycle tends to compensate for the absence of density terms in the discharge model and permits a one-dimensional, constant-density, transient-flow model to be used to compute discharge in the estuary at Astoria, Oreg.

Hydrologic factors related to radioactive waste storage in basaltic rocks at the Hanford Reservation, Wash.

A. M. La Sala, Jr. (r2066), and G. C. Doty conducted hydraulic tests in a deep test well, drilled at the Hanford Reservation, Wash., by the U.S. Atomic Energy Commission, to investigate the possibility of safely confining and isolating radioactive wastes in a deep mined cavern in basalt. The well was drilled to a depth of 5,661 feet and tested to a depth of 4,280 feet by isolating selected sections between inflatable packers and injecting a slug of water into the isolated section through a string of tubing. The transmissivity was computed from the rate of change in head following the injection of a known volume of water. The hydraulic conductivity of the rock units penetrated ranged from 1.6×10^{-3} to 6.7 fpd, as computed from the injection test data. Relatively permeable zones occur at depths of about 1,500, 2,050, 3,200, and 4,000 feet. The static head in the upper basaltic rocks is about 165 feet below the surface. The depth to water changes little in the water-bearing zones to a depth of 3,700 feet; however, in the permeable zone at a depth of about 4,000 feet, the head has decreased to 206 feet below land surface.

The lowest head measured in the well is above the level of the Columbia River to the southeast, suggesting that the ground water may be part of a system discharging to the river. Chemical analyses of water samples collected from different zones showed that these ground waters are high in silica, fluoride, bicarbonate, carbonate, and pH, and that they have low calcium-to-sodium and calcium-to-magnesium ratios. Water from a zone at a depth of 540 to 620 feet had an adjusted carbon-14 age of about 13,000 yr.

SITES FOR NUCLEAR POWER REACTORS AND OTHER FACILITIES

The U.S. Geological Survey has been reviewing geologic and hydrologic aspects of license applications to the U.S. Atomic Energy Commission for nuclear facilities such as power reactors, fuel processing plants, and solid-waste burial grounds. These reviews evaluate geologic and hydrologic phenomena which are related to the safety of the facility. Included in the evaluations are faulting seismic activity, flooding, availability of water for cooling, and foundation conditions, as well as the potential extent of contamination of water resources that could occur through the operational or accidental release of radionuclides.

During the year, E. H. Baltz, Jr., P. J. Carpenter, F. A. Kilpatrick, and H. H. Waldron prepared reviews of the geologic and hydrologic aspects of sites for 18 proposed nuclear powerplants and 3 nuclear-fuel reprocessing plants. Experience indicates that regional and local geologic and hydrologic knowledge, applied to the evaluation of specific sites, allows the engineering design criteria for nuclear facilities to be closedly adapted to the environment, with a resulting increase in safety and potential decrease in costs of construction and design.

FLOODS

Three major categories of floods studied by the U. S. Geological Survey are (1) measurement of stage and discharge, (2) definition of the relation between the magnitude of floods and their frequency of occurrence, and (3) delineation of the extent of inundation of flood plains by specific floods, or by floods having specific recurrence intervals.

OUTSTANDING FLOODS

Outstanding flood on small stream in southern Johnson County, Iowa

A flood discharge estimated to be 1.3 times that of the 50-yr flood occurred March 3, 1970, on Old Mans Creek in southern Johnson County, Iowa. The town of Hills, near the mouth of the creek, was not inundated. H. H. Schwob (r0391) obtained high-water elevations and discharge data, documenting the flood.

Flood of March 19–20, 1970, metropolitan Birmingham and Jefferson County, Ala.

K. W. Causseaux reported that rainfall in Jefferson County on March 19, 1970, ranging from 6 to 10 inches, resulted in flooding throughout Jefferson County. Concentrations of intense rainfall caused flash floods in many localities. The recurrence interval of the 12-hr rainfall at the Birmingham municipal airport was about 40 yr.

Flood damages in Birmingham and Jefferson County were estimated at $5 million to private property and more than $1 million to public property.

The magnitudes of peak flows were determined at 14 places in Jefferson County, flood profiles were defined on all major streams, and inundated areas were delineated on 7½-minute topographic maps. The flood is generally considered to have a recurrence interval of about 25 yr, although recurrence intervals of peak flows at some sites ranged from 5 to 50 yr.

Floods of June-July 1969 in northeastern Iowa

Three large storms in northeastern Iowa on June 22–30, July 6–9, and July 15–18, 1969, resulted in many peak discharges exceeding those of the 50-yr flood. Record monthly rainfalls ranging from 12.60 to 13.55 inches were reported.

According to A. J. Heinitz, record stages on the Iowa River occurred at the Marshalltown and Marengo gaging stations. Some homes in Marshalltown and Tama were damaged. The town of Chelsea, with a population of about 450, was almost completely flooded. Many homes and businesses were inundated to a depth of several feet above the first floor.

Coralville Reservoir on the Iowa River, completed in 1957, was filled to a record capacity when it crested at 711.85 feet above mean sea level on July 21, 1969. The ungated overflow spillway is at elevation 712 feet.

Floods of September 1970 in Arizona, Utah, and Colorado

On September 4–6, 1970, heavy rains caused floods in southern and central Arizona, southeastern Utah, and southwestern Colorado. The most severe floods occurred in central Arizona, where 11.40 inches of rain were recorded in 24 hr at one station—an alltime record for Arizona. In southeastern Utah 6 inches of rain was measured in 12 hours, which is a new 12- and 24-hour record for Utah. As a result of the floods 23 lives were lost in central Arizona and 2 lives were lost in southeastern Utah. Damage to roads, railroads, irrigation canals, public utilities, homes, and farmland was in the millions of dollars. The President declared parts of Arizona and Colorado disaster areas. R. H. Roeske reported that peak discharges of several hundred cfs per sq mi were measured at many stations in central Arizona, and the peak discharges exceeded those of a 100-year flood at several stations. On September 12–14, 1970, a second storm of lesser magnitude caused floods in southwestern Colorado and southeastern Utah.

FLOOD-FREQUENCY STUDIES

Flood definition in California from botanical and geomorphic evidence

Deposits left by prehistoric floods at four locations in northern California have been recognized and documented by E. J. Helley and V. C. LaMarche, Jr. The times of these flood events, determined by dendrochronologic and carbon-14 dating, range from about 100 to 500 yr.

Estimating magnitude and frequency of floods in Wisconsin

Equations have been developed by D. H. Conger (r2031) for estimating flood discharges for selected recurrence intervals up to a 50-yr flood for drainage areas 0.5 sq mi and larger in Wisconsin.

Tidal flooding along the Georgia coast

In a study of the frequency of high-tide elevations along the Georgia coast, McGlone Price found that the 100-yr storm-tide elevation varied from about 10 feet above mean sea level at the Georgia-Florida State line to about 13 feet above mean sea level at the Georgia-South Carolina State line. Historical data on storms along the Georgia coast date back to 1752, but these data show that a long record does not necessarily reveal all of the potential danger. The 1893 hurricane tide is estimated to have attained an elevation of 19.5 feet on the open beach at Savannah, Ga. Data are not available to predict the attenuation of hurricane tides as they move inland.

Generalized flood-frequency relations for urban areas in Missouri

Limited flood data for urban streams in Missouri support the applicability of the Leopold diagram[159] to Missouri streams. Using the Leopold diagram, E. E. Gann developed generalized relations for estimating flood-frequency information for urban areas in Missouri. The relations provide an estimate of peak discharge for floods with recurrence intervals ranging from 2.33 to 100 yr for basins with various degrees of existing or projected urban development. The generalized relations will be useful to the urban planner and designer.

[159]Leopold, L. B., 1968, Hydrology for urban land planning—A guidebook on the hydrologic effects of urban land use: U.S. Geol. Survey Circ. 554, fig. 2, p. 5.

Flood-flow characteristics in small basins in Massachusetts, Rhode Island, and Vermont

C. G. Johnson and G. A. Laraway are conducting a study to develop a technique for estimating the magnitude and frequency of floods on small drainage areas in Massachusetts, Rhode Island, and Vermont.

A network of continuous-recording stream gages equipped with recording rain gages (10 gages in Massachusetts, 5 in Rhode Island, and 11 in Vermont) have been maintained for the past 6 yr on streams draining areas of 10 sq mi or less. In addition, 95 crest-stage gages have been maintained at similar sites, where basins were carefully selected so that a typical range of physiographic variables could be sampled. The data collected have been analyzed and published in the annual basic-data releases.

Flood characteristics of small streams were compared with those of streams having drainage areas in excess of 10 sq mi. Flood-frequency curves prepared for the smaller streams by using the existing 6 yr of data were plotted against those obtained by using regression equations recently developed in an analysis of the characteristics of larger streams in central New England. In addition, station-frequency curves prepared for the larger streams, using the same 6 yr of record, were plotted against those obtained from the regression equations.

The initial results indicate: (1) a possible time-sampling bias due to a series of "dry years" at the outset of the project, and (2) a need for a slight redefinition of the equations before they can be applied to smaller streams.

Flood data for the Wapsipinicon River basin, Iowa

Profiles, discharges, and frequencies of floods on 338 mi of the main stem and six tributaries in the Wapsipinicon River basin, tabulated by H. H. Schwob (r2096), furnish data for design of structures on or across the flood plain. Profiles and discharge data for notable floods in 1968 and 1969 are supplemented by similar data computed for the 24- and 50-yr floods. The basin is primarily agricultural with several small cities and towns affected by flooding.

FLOOD MAPPING

Channel capacities of the Fresno and Chowchilla Rivers in California

The floodflow capacity of the Fresno and Chowchilla Rivers, Madera County, Calif., is described in two channel capacity reports by G. L. Bertoldi (r2019) and J. C. Blodgett. Results are based on records of streamflow, and historical and computed flood elevations. Maps, profiles, cross sections, and stage-discharge relations show the extent of 1969 flooding and indicate the probable extent of flooding that may occur in the future. The flood data may be used to define the primary floodway, minimize vulnerability to flood damages by flood-plain management regulations, zoning regulations, and building codes. The data will assist individuals, industry, and government in the planning of recreational and waste-disposal facilities and flood-protection works.

Flood maps at Cedar Rapids, Iowa

Maps and water-surface profiles contained in a report by H. H. Schwob[160] show the potential inundation by a great flood on Morgan Creek (drainage area 18.9 sq mi). Flood profiles for a restricted waterway also are shown for a smaller flood. The study area is located near the northwestern edge of Cedar Rapids, Iowa, in an area of expected urban development.

Flood maps for small streams near Cedar Rapids, Iowa

Potential flooding by a great flood on Hoosier and South Hoosier Creeks (drainage area range 1.1 to 17.9 sq mi) is indicated by water-surface profiles, and maps by H. H. Schwob (r0358). Profiles for a floodway restricted by encroachments are shown for a smaller flood. The area studied is one of potential urban development located adjacent to the south boundary of Cedar Rapids, Iowa.

Floods on Yahara River, Wis.

J. O. Shearman, B. K. Holmstrom, and C. L. Lawrence defined the profile and approximate outline of the flooded area for the regional (100-yr) flood along a 17-mi reach of the Yahara River, Dane County, Wis., from the head of Lake Mendota upstream to U.S. Highway 51. Many constrictions and variable topography are reflected in an irregular profile of from 5 to 14 feet above normal low-water elevation.

Flood of March 1968 on Charles River in eastern Massachusetts

The extent of flooding along the main stem of Charles River in Massachusetts during March 1968 was delineated on photomosaic maps by L. A. Swallow (r2325), R. G. Petersen, and G. H. Searles. Maximum flow at the gaging station at Waltham on March 22, 1968, was the greatest since 1887. Maps, frequency information, hydrographs, and flood-height data provide a technical basis on which to make flood-plain management decisions.

Inundated areas along the Charles, Sudbury-Assabet-Concord, Ipswich, Neponset, Taunton, and Blackstone Rivers have been delineated on photomosaic maps for publication in six separate reports of the Hydrologic Investigations Atlas series.

[160]Schwob, H. H., 1970, Flood-profile study, Morgan Creek, Linn County, Iowa: U.S. Geol. Survey open-file rept., 16 p.

Maps of flood-prone areas

Areas inundated by the 100-yr flood are outlined on topographic maps as part of the National Program for Managing Flood Losses. The objective of this activity is quickly to inform cities and towns of the general extent of their potential flood problems. More than 3,300 such maps have been completed in 46 States.

Inundation maps of urban areas

Maps showing areas inundated by major floods, flood profiles, discharge-frequency relations, and stage-frequency relations were published during the current year as Hydrologic Investigations Atlases for the following areas: Hebron, Ill. (H. E. Allen, r1999, and R. S. Grant); Channahon, Ill. (H. E. Allen, r1286, and A. W. Noehre); Añasco, P. R. (F. K. Fields, r2000); Yabucoa, P. R. (F. K. Fields, r1284); Guayama, P. R. (W. J. Haire, r0779); Guayanilla-Yauco, P. R. (F. K. Fields, r1647); Patillas-Maunabo, P. R. (W. J. Haire, r0778); Salinas, P. R. (W. J. Haire, r0780); Santa Isabel, P. R. (W. J. Haire, r0781); Ellijay, Ga. (McGlone Price, r2003); northeastern Jefferson County, Wis. (J. O. Shearman, r1648, and B. K. Holmstrom); southwestern Jefferson County, Wis. (J. O. Sharman, r1283, and B. K. Holmstrom); Charles River, Mass. (L. A. Swallow, r2325, R. G. Petersen, and G. H. Searles); Huntley, Ill. (G. L. Walter, r1287, and R. T. Mycyk).

WATER QUALITY AND CONTAMINATION

The development and use of water in many areas are restricted or complicated by the presence of undesirable waste products, including heat, and natural constituents in surface and ground waters. To study these undesirable water contaminants, the U.S. Geological Survey conducts basic research and areal investigations that define the causes and the extent of contamination in the environment.

Pesticide monitoring of streams in the Western United States

Monitoring of pesticides in solution at 20 selected stations on streams in the Western United States was continued during the period October 1968 to September 1970. In studies reported by Jean Schulze and D. B. Manigold, each monthly sample was analyzed for the insecticides aldrin, DDD, DDE, DDT, dieldrin, endrin, heptachlor, heptachlor epoxide, and lindane; and the herbicides 2, 4-D, 2, 4, 5-T, and Silvex. Each pesticide, except heptachlor and heptachlor epoxide, was detected at least once, and every stream contained pesticides at least at one sampling. DDT was the most frequently occurring insecticide, and 2, 4-D was the most frequently occurring common herbicide.

The highest concentration of DDT observed was 0.46 μg/l; the highest concentration of 2, 4-D was 0.99 μg/l. Insecticides accounted for 53 percent of the pesticide occurrences, and herbicides accounted for 47 percent. During the previous reporting period, October 1967 to September 1968, insecticides made up 70 percent of the occurrences and herbicides only 30 percent. In July 1970, routine monitoring of phosphorothioate insecticides was added to the study. Methyl parathion and parathion were detected in two streams.

Increasing contamination in the principal aquifer in Nassau County, N.Y.

Residual contaminated water in the upper glacial aquifer in a sewered area, and increasingly contaminated water in the same aquifer in an adjoining unsewered area, have seeped down nearly 600 feet below land surface to form a major body of contaminated water in Nassau County's principal source of supply, the Magothy aquifer.

Contaminants, chiefly from sewage, fertilizers, landfills, and storm water, are responsible for a significant increase in hardness, chloride, sulfate, nitrate, and other dissolved constituents in the water, according to N. M. Perlmutter and Ellis Koch. (See related study, p. D171–D177.) High-nitrate water, as much as 94 mg/l in places, has resulted in shutdown, reduced pumping, or deepening of several public-supply wells. Advance of the southward-moving "nitrate front" may not be significant near the south shore if the nitrate is converted to ammonium by natural chemical reduction and, subsequently, is removed from the water by sorption or ion exchange. In contrast to other contaminants, no significant concentrations of either MBAS (detergents) or phosphate were found in water from the Magothy aquifer.

Organochlorine insecticide residues in Loxahatchee National Wildlife Refuge and adjacent areas, Florida

A. L. Higer and M. C. Kolipinski found that water in Loxahatchee National Wildlife Refuge and Everglades National Park, Fla., contained DDT and its metabolites, DDD and DDE, in the range 0.00 to 0.03 μg/l between December 1966 and October 1968. Some samples of soils underlying marshes in these areas had concentrations of DDT-family compounds (that is, DDT, DDD and DDE) as much as three orders of magnitude greater than the concentrations found in water. Also, algal mats at the base of food chains and omnivorous marsh-dwelling crustaceans showed some accumulations of DDT-family compounds as much as three orders of magnitude greater than the trace concentrations found in water. Marsh fishes, intermediate in Everglades aquatic food chains, were found to have concentrations of DDT-family compounds as much as four orders of magnitude greater than the concentrations found in water. The highest concentrations of the DDT-family compounds are found in the higher carnivores and omnivores. The basic contribution of the data is in showing that organochlorine insecticide residues are present in all trophic levels of the Everglades aquatic environment.

Mercury content of waters of Long Island, N.Y.

The mercury content of precipitation and surface and ground waters of Long Island, N.Y., is much less than the U.S. Public Health Service tentative limit for drinking water of 5.0 μg/l. According to C. A. Harr, the mercury content of water collected during August 1970 from sources broadly representative of the geologic and hydrologic environment of Long Island ranged from less than 0.1 to 0.5 μg/l. Although there is no apparent relation between the source of water and the mercury content, ground water contained an average of about 0.3 μg/l, surface water an average of about 0.4 μg/l, and precipitation an average of about 0.4 μg/l.

Geochemical survey of Missouri waters

Results obtained in an environmental geochemical study of ground water in Missouri indicate the importance of complete nitrogen-cycle determinations in order to evaluate potential pollution.

G. L. Feder reported that ground waters containing less than 1 mg/l nitrate and virtually no nitrite contained as much as 12 mg/l organic nitrogen (as N), and 8.7 mg/l ammonia nitrogen (as N). The high organic and ammonia nitrogen values are associated with reducing ground-water environments containing hydrogen sulfide. Where conditions are reducing, ammonia and organic nitrogen are chemically stable with respect to nitrate and total nitrogen. Organic nitrogen or ammonia may serve as more reliable pollution indicators. None of these indicators are totally reliable as each of the constituents may occur in high concentrations through natural processes, but manmade pollution may be immediately suspected when high concentrations are found.

Effects of acid-mine drainage on stream fauna in Pennsylvania

Acid discharges from abandoned coal mines to three Pennsylvania streams were found to eliminate or severely restrict the fish and benthic fauna in areas along many miles of streams that would otherwise be highly desirable for recreation. A study by J. L. Barker showed that benthic organisms tolerant to pH values down to 4.1 included species of Plecoptera, Trichoptera, Diptera, Megaloptera, and Annelida. Notably absent in the highly acid waters and therefore considered intolerant were representatives of the order Ephemeroptera.

Fish were virtually eliminated from the stream reaches inhabited by the tolerant benthic organisms. The white sucker, *Catostomus commersoni*, was found to be the most tolerant of the native fishes to the highly acidic environment.

Statistical and sensitivity analysis of reaeration coefficient data

J. P. Bennett and R. E. Rathbun conducted a sensitivity analysis of the dissolved-oxygen balance and disturbed-equilibrium techniques for determination of the reaeration coefficient. They found the most significant source of error in the reaeration coefficient determined by the dissolved-oxygen technique to be the production of dissolved oxygen by photosynthesis. Other sources of error in decreasing order of significance were errors in the dissolved-oxygen deficit at the upstream end of the reach, the dissolved-oxygen deficit at the downstream end of the reach, the rate constant for biochemical oxidation of carbonaceous wastes, and the biochemical oxygen demand of the waste at the upstream end of the reach. For the disturbed-equilibrium technique, the sources of error, in decreasing order of importance, were errors in the dissolved-oxygen deficit at the downstream end of the reach, net production of dissolved oxygen by photosynthesis, the dissolved oxygen at the upstream end of the reach, and the traveltime through the reach.

The investigators also found a significant difference between regression equations for the reaeration coefficient based on flume data and equations based on natural stream data. The most probable reasons for this difference were scaling problems, statistical quirks because of the complex interdependent relations of the variables, and experimental bias in one or more of the data sets. From a regression analysis of all available data for natural streams, the recommended equation for the prediction of the reaeration coefficient is $K_2=8.76V^{0.607}/H^{1.689}$ when K_2 is in days^{-1} and is for 20°C, V is the mean velocity in feet per second, and H is the mean depth of flow in feet.

ENVIRONMENTAL GEOCHEMISTRY

Geological Survey participation in organized interdisciplinary information exchange

A National Research Council Subcommittee on Geochemical Environment in Relation to Health and Disease, chaired by H. L. Cannon, planned and organized a symposium which was held in connection with the American Association for the Advancement of Science (AAAS) meetings in Chicago (H. L. Cannon, r1138, and H. C. Hopps). The symposium covered many important aspects of environmental geochemistry and geographic pathology. Calcium, phosphorus, iron, copper, and all the other important inorganic nutrients somehow make their way from their original source in the rock substrate through soils and waters into plants, animals, and finally, man. How is this transfer accomplished and how readily do the various elements move into and through the food chain? What effects do climate and time have on this movement? What sort of interactions take place between the various elements to enhance or hinder this process? How are these elements utilized by different kinds of organisms and what effects do even small excesses or deficiencies of any one element have on the health of plants or animals? These questions, raised during the symposium, involve environmental scientists in many parts of the world. If we are to answer these questions, it will require the rapid and effective exchange of information between workers in many disciplines.

Probably the least known factor affecting the nutrition of organisms is that of element availability in each transfer from one medium to another. How is the basic chemical behavior of the element at each step in the transfer affected by the physical and biological microenvironment in which it occurs? Some elements are released from rock-forming minerals during weathering more readily than others, and some cations are bound more tightly than others in residual clays. At the AAAS meeting in Chicago, J. D. Hem discussed a particularly important control, the behavior of iron and manganese in water under different conditions of pH and Eh, on the availability of many metals. As more sensitive chemical tests are becoming available, geographic areas that have occurrences of many minor metals in anomalous concentrations are being recognized, and the possible health effects of deficiencies of many metals, previously recognized as harmful only in large excesses, are being studied. Deficiency of selenium, for example, causes white muscle disease in animals in interior and Eastern States, whereas in certain Western States where the soils contain high concentrations of selenium, it is readily absorbed by plants in amounts that are toxic to animals. H. W. Lakin reviewed the problem of selenium toxicity and reported that selenium poisoning through the food-plant cycle is rare in the human populations of the world and tends to be restricted to highly seleniferous areas where the populations depend largely on local agricultural produce. Selenium in appreciable quantities is being released in our environment daily by burning petroleum products, solid wastes, and coal, but probably not in hazardous concentrations. However, the possible effects of selenium in combination with other contaminants in the atmosphere and waters are not known. The possibility of causal relationships between naturally occurring concentrations of minor metals (such as Cd, Cr, Mo, Sr, As, F, and L) and the occurrence of many degenerative diseases in man is slowly being recognized.

H. T. Shacklette reported on a continuing study of the geochemical environment and cardiovascular mortality rates in Georgia.[161] Water analyses available in the counties under study were not sufficient for statistical evaluation. No elements alleged to be harmful to cardiovascular functions were found in high concentrations in the high-death-rate area, although Cd, F, and Se analyses are unavailable. Garden vegetables failed to reflect clearly the chemical compositions of the soils on which the vegetables grew. Of those trace elements alleged to have beneficial effects on cardiovascular function, Mn, Cr, V, and Cu were more highly concentrated in soils from the low-death-rate counties. If geochemical differences between the soils of the two areas do, in fact, have a causal relationship to death from cardiovascular diseases, the cause would appear to be a deficiency, rather than an excess, of the elements that were studied. The study pointed out the need for water analyses in this type of investigation and showed that, with the appropriate multidisciplinary teamwork,

[161]Shacklette, H. T., Sauer, H. I., and Miesch, A. T., 1970, Geochemical environments and cardiovascular mortality rates in Georgia: U.S. Geol. Survey Prof. Paper 574-C, p. C1–C39.

the geographic patterns of element distribution in the physical environment can be compared with those of animal and human disease.

Lead contamination along highways

A report was issued in 1962 by H. L. Cannon and J. M. Bowles on the lead content of grass that had been sampled in 1961 for a distance of 1,000 feet south from Sixth Avenue at a site west of Denver, Colo.[162] The same stations were resampled in 1969. The average lead content of grass along the 1,000-foot traverse has risen nearly 1,000 percent in the 8-yr interval; that of zinc, 260 percent, and of iron, 157 percent. Increased levels of Pb, Zn, Fe, and also Cd extend over the entire traverse. Also, Ni, Sr, and Mg contents in grass within 100 feet of the highway are greater than those in grass more distant from the highway.[163]

J. J. Connor, H. T. Shacklette, and J. A. Erdman (p. B151–B156), in a study of roadside effects on element concentrations in plants, reported that the unusually high concentrations of Pb, Cu, Zn, and Cd detected in a sample of a roadside cedar tree collected near Centerville, Mo., have been confirmed by new analyses of additional samples. These concentrations are much greater than those expected to result from vehicular exhaust emissions alone and are thought to reflect vehicular transport of lead-bearing ore material from mine to smelter.

Uranium enrichment in weathered phosphatic limestones

Calcareous phosphorites are generally less uraniferous than other marine phosporites. Z. S. Altschuler reports, however, that upon weathering these rocks develop highly uraniferous zones. During supergene alteration the apatite dissolves at the surface, and the phosphate is deposited at shallow depths at the base of the zone of weathering in the form of apatite hardpans and phosphatized limestone. The uranium reconcentrated from solution in these secondary deposits attains concentrations as high as 0.05 to 0.15 percent (500–1,500 ppm) in the Cooper Marl of South Carolina. These subsoil hardpans and replacement bodies develop in river valleys where the population may be dense. Moreover, they are overlain by thin and extensively leached mantles, which are therefore highly porous and permeable. In consequence, a significant increase in radioactivity at ground level may be anticipated in these areas, and such deposits warrant detailed study as potentially critical factors in environmental health.

Mercury in surficial materials in the United States

Mercury concentrations in 912 samples of soils and other regoliths from locations approximately 50 mi apart throughout the conterminous United States were reported by H. T. Shacklette (r1752), J. G. Boerngen, and R. L. Turner. Sampling sites were selected, insofar as possible, to represent surficial materials that were little altered from their natural condition, and samples were collected at a depth of about 8 inches. Above-average concentrations of mercury were found in surficial materials from the Gulf coastal, New England coastal, Pacific coastal, and Great Lakes regions, whereas average or lower concentrations generally were found in samples from the Great Plains region and the Columbia Plateau. The geometric mean concentration of mercury in all samples was 71 ppb; samples from locations east of the 97th meridian averaged 96 ppb, and those west of this meridian averaged 55 ppb. The greatest concentration found was 4,600 ppb, but 11 other samples contained 1,000 ppb or more. This study did not attempt to differentiate the effects of mercury contamination from those of natural geologic processes.

Mercury in plants

H. T. Shacklette (r0677) determined the characteristic mercury contents of land plants that grow in both normal environments and in environments that contain abnormal amounts of mercury. He reported that in environments containing normal amounts of mercury, few plants exceed 500 ppb Hg in their dried tissues. In environments that have significantly larger amounts of mercury because of the natural occurrence of mercury-bearing deposits, the plants may contain between 500 and 3,500 ppb Hg in their dried tissues. Much larger amounts of mercury may be found in plant samples as surficial residues or as deposits in the tissues as a result of intentional application of mercury compounds or from contamination.

Mercury in phosphorites

According to J. B. Cathcart, mercury analyses by R. L. Turner of samples of phosphate concentrate from the land-pebble field of Florida ranged from 80 to 740 ppb; samples of concentrate from North Carolina contained from 70 to 1,000 ppb, and samples of phosphorite from the Phosphoria Formation contained from 100 to 2,800 ppb. Samples of phosphorite from Colombia contained from 40 to 610 ppb, and samples of phosphorite from Brazil contained from 50 to 160 ppb. Although these data have not been completely analyzed, there seems to be no correlation between contents of mercury and P_2O_5, but there does seem to be a correlation between mercury content and the amount of total organic material. The samples from the Phosphoria Formation contain the highest concentrations of mercury and are high in organic material; samples from North Carolina also contain rather abundant organic material. Samples from Florida and Colombia are somewhat low in organic material, whereas the samples from Brazil, containing the lowest contents of mercury, are nearly devoid of organic material.

[162] Cannon, H. L., and Bowles, J. M., 1962, Contamination of vegetation by tetraethyl lead: Science, v. 137, p. 765–766.

[163] Cannon, H. L., and Anderson, B. M., 1971, The geochemist's role in the pollution problem: Geol. Soc. America Memoir. [In press]

Environmental geochemistry in Missouri

Background data on the distribution of elements in soils throughout the State of Missouri are being gathered by R. R. Tidball to support studies by the University of Missouri on the distribution of diseases in animals and humans. A preliminary sampling plan was carried out to determine whether taxonomic groups of soils, defined on the basis of several morphologic properties, are also distinct in chemical composition. If the groups are chemically distinct, then the Soil Classification System[164] (a hierarchical taxonomy) can be used as an efficient basis for sampling to estimate variation in chemical composition within and between groups of soils. Sampling categories of soils at some high taxonomic level, such as suborders, would reduce the total sample load in a statewide sampling program compared to sampling at some lower taxonomic level, such as series, and might be nearly as informative.

The results indicate that for most elements studied less than 50 percent of the total variation in chemical composition can be described by sampling at the suborder level. This means that the factors which control the chemical compositions of soils are not entirely the same as those that control the morphologic properties on which the definitions of soil suborders are based. Suborders of the Soil Classification System, therefore, are not considered to be well suited as a basis for sampling soils in environmental studies. An alternative soil classification system which includes parent material as a more important factor of classification is being evaluated.

J. J. Connor, R. J. Ebens, and J. D. Sims noted a marked difference in the minor-element content of the two most widespread surficial deposits in Missouri: (1) loess in the northern half of the State and along the Mississippi River valley, and (2) carbonate residuum (red, cherty, deep soil) over much of the southern half of the State. The loess is richer by a factor of two or more in the alkali (Na,K) and alkaline-earth (Ca, Sr, Ba) metals as well as in P, B, Ga, Mn, and Zr. It is lower by a factor of two or more in the transition metals (Fe, Cu, Ni, V, Zn) and in As and Be. The differences in the soluble alkali and alkaline-earth metal contents may reflect the marked contrast in exposure to the weathering process, because the residuum has probably been forming for millions of years, whereas the loess has been exposed for only a few thousands of years. The reason for the higher concentrations of transition metals in the residuum is not well understood, but this may reflect long-continued residual accumulation of elements during residuum development inasmuch as the carbonate parent rocks appear to be generally poor in commonly detected minor elements as compared with other sedimentary rocks.

[164]Soil Survey Staff, 1960, Soil classification, a comprehensive system, 7th approximation: Soil Conservation Service, U.S. Dept. Agriculture, 265 p.

LAND SUBSIDENCE

Studies of land subsidence caused by decrease of artesian head are contributing to knowledge of the physical and hydrologic properties of leaky compressible aquifer systems, primarily through observing the response of these systems to change in applied stress.

The volume of subsidence is a measure of the quantity of ground water yielded from storage by compaction of the fine-grained beds in aquifer systems. This volume can be very large. In the San Joaquin Valley of California, for example, the volume of water yielded through subsidence to 1970 is about 13 million acre-ft and currently averages about 450,000 acre-ft per yr.

Sinkhole problem in and near Roberts industrial subdivision, Birmingham, Ala.

Sinkholes in and near Roberts industrial subdivision along Village Creek in Birmingham, Ala., have resulted in costly damage, major pollution, and narrowly averted accidents, according to J. G. Newton (r2085) and L. W. Hyde. Lowering of the water table about 140 feet as a result of ground-water withdrawals makes the area prone to development of sinkholes; more than 200 collapses and areas of subsidence formed within less than half a square mile during 1963–70. The formation of sinkholes results from the collapse of roofs of cavities in residual clay. The cavities have been created by spalling or the downward migration of clay through openings in underlying carbonate rocks. The spalling and formation of cavities is caused by, or may be accelerated by, a lowering of the water table, resulting in loss of support to clay overlying openings in bedrock, fluctuation of the water table against the base of residual clay, and increased velocity of water in cones of depression to points of discharge. Collapses have occurred where spalling and the resulting enlargement of cavities has progressed upward until overlying clay will not support itself and where vibrations, shock, or loading over cavities cause the clay to be jarred loose or forced down.

Canal deliveries affect subsidence rates in the Tulare-Wasco area, California

Subsidence rates have greatly diminished in 20 percent of the Tulare-Wasco area, California, receiving surface water from the Friant-Kern Canal, according to a recent subsidence map prepared by B. E. Lofgren. The map, based on leveling by the U.S. Coast and Geodetic Survey in 1962 and 1970, clearly defines the areal extent of subsidence and the subsidence holes where ground-water mining continues.

During the 8-year period 1962–70, the volume of subsidence averaged 108,000 acre-ft per yr. This volume is considerably less than the 173,000 acre-ft per yr average for the 1959–62 period, but about twice the rate for the 1954–59 period.

Even though subsidence rates are reduced in areas receiving surface water, this decrease is roughly offset by increased subsidence in unserved areas.

Subsidence in the Arvin-Maricopa area, California

As of March 1970, maximum subsidence in the Arvin-Maricopa ground-water basin south of Bakersfield, Calif., was more than 9 feet, and the cumulative volume of subsidence since 1926 was 1 million acre-ft, according to studies by B. E. Lofgren. From March 1965 to March 1970, the rate of subsidence, resulting from the mining of ground water from the basin, averaged 46,800 acre-ft per yr, which was about the same as for the previous 3 yrs.

Compaction recorders, which measure the rate of compaction at specific depth intervals, suggest that since 1962, rates have increased in the deeper water-bearing deposits and decreased in the shallower zones. This change is probably caused by the drilling and pumping of larger and deeper irrigation wells, which cause pressure reductions at greater depths.

Water imports have nearly arrested subsidence in Santa Clara County, Calif.

Water imports to Santa Clara County, Calif., have increased fourfold in 5 years—from 30,000 acre-ft in 1964–65 to 124,000 acre-ft in 1969–70 – a volume equal to about 70 percent of the pumpage in the early 1960's. As a result of the increasing imports and above-average precipitation, recharge increased and pumpage decreased substantially. A water charge applied to ground-water pumpage helped to finance the costs of importing water and was effective in reducing pumpage. In response, the spring-high artesian head in the San Jose area rose about 70 feet from 1967 to 1971.

Although the bench-mark net has not been releveled since 1967, compaction recorders operated by the Geological Survey since 1960 in cased holes 1,000 feet deep in San Jose and Sunnyvale serve as continuous subsidence recorders. At these sites, the rate of subsidence has decreased about 95 percent in the past 10 years, according to J. F. Poland. At San Jose, the rate decreased from about 1 ft per yr in 1961 to about 0.07 ft per yr in 1970. At Sunnyvale, it decreased from about half a foot per year in 1961 to 0.02 ft per yr in 1970.

Subsidence in the San Bernardino area, southern California

Extensive ground-water withdrawals and resulting head declines have produced small, but widespread, land subsidence in the Chino-Riverside and Bunker Hill–Yucaipa areas, California. Maximum observed subsidence is immediately east of the San Jacinto fault near Loma Linda and according to B. E. Lofgren (r2071) totaled about 1.3 feet from 1943 to 1968–69.

The aquifer system consists of poorly consolidated alluvial deposits ranging in thickness from about 100 to 1,200 feet. Subsidence rates are influenced by the thickness and compressibility of the water-bearing deposits but show a close correlation with water-level declines in the area.

The study was made by the U.S. Geological Survey at the request of the California Department of Water Resources to estimate how much future subsidence might occur if postulated severe pumping stresses were imposed on the ground-water basin. Ratios of subsidence to head decline, computed during historic periods of measured bench-mark settlement and water-level change, indicated that more than 4 feet of subsidence would occur in the vicinity of San Bernardino by the year 2015 if these postulated stresses were imposed, according to estimates by B. E. Lofgren.

According to R. E. Miller (r2508) and J. E. Singer, who made studies in cooperation with the San Bernardino Valley Municipal Water District in the Bunker Hill–San Timoteo area, damage to drains, sewers, flood-control structures, and pipelines could result from the predicted subsidence.

Subsidence in the area could be halted by a permanent recovery of water levels. However, on the basis of projected water-level declines, the best method of minimizing subsidence would be by developing a pumping pattern that would distribute the drawdown effect more evenly across the study area.

ASTROGEOLOGY

LUNAR EXPLORATION

Apollo lunar geology experiment

The program of lunar exploration being conducted by the National Aeronautics and Space Administration (NASA) was continued in 1970 with two missions scheduled, but in April Apollo 13 returned without landing on the lunar surface, and Apollo 14 was postponed until early 1971. The data resulting from the prior Apollo 11 and 12 missions were analyzed during the year by members of the Apollo lunar geology experiment team, E. M. Shoemaker, principal investigator. Preliminary results from the Apollo 12 mission were summarized by Shoemaker and others (r2509) and by H. E. Holt (r2506) (USGS) and J. J. Rennilson (California Institute of Technology). Continued study by G. A. Swann (r1048, r2511), G. G. Schaber, and R. L. Sutton during the year produced refined data and additional interpretations.

Crystalline rock and shock-indurated regolith material, or breccia, were nearly equally represented in the fragments collected within a 20-m radius of the Apollo 11 spacecraft. Only three fragments of breccia were collected at the Apollo 12 site; crystalline basaltic rocks compose most of the samples returned, and some cumulate rocks apparently were derived from distant sources. The Apollo 12 site is crossed by a ray from the crater Copernicus, 370 km north, but the ray was not directly observed on the ground. According to G. A. Swann, rays probably are visible on orbital photographs as a result of integration of bright block-strewn fields, abundant small secondary craters, shock-melted glassy materials, and, possibly, light-colored ejecta.

A map of the Apollo 12 site at a scale of 1:2,000 prepared by R. L. Sutton shows the traverse route and location of samples in detail and in relation to the larger craters to which sampling extended in this part of Oceanus Procellarum. Lunar orientation of nine samples prior to collection has been determined; orientation of 12 additional rocks is tentatively suggested by Sutton and G. G. Schaber, who confirm the conclusion of several investigators that the position of a rock at time of collection may have been attained recently in terms of its total exposure on the lunar surface.

The sample locations combined with the morphology of the local craters and the petrography of the individual rocks provided H. H. Schmitt (NASA) and Sutton with a basis for inferring a vertical sequence of flows at both the Apollo 11 and 12 sites. Subject to chemical and age determinations, the sequence at the Apollo 11 site is considered to be (from the top down) basalt, olivine basalt, crystobalite gabbro, and olivine gabbro. Two flows appear to be present at the Apollo 12 site: the upper, characterized by a surficial zone of vesicular olivine basalt porphyry, and the lower, by a surficial zone composed of clinopyroxene-olivine basalt porphyry.

H. E. Holt and J. J. Rennilson began to measure photometric properties of representative lunar samples. The spectral reflectance is larger at longer (red and infrared) wavelengths than at shorter (blue) wavelengths. The degree of polarization of the reflected light varies with phase angle and is secondarily affected by specular reflection from glassy or crystalline material.

Studies of the processes of regolith formation on the lunar maria have suggested to E. M. Shoemaker and M. H. Hait that there must be a vertical decrease in the mean size of fragments and a vertical increase in the proportion of exotic fragments and meteoritic material. They conclude that the flux of particles bombarding the lunar surface has declined exponentially with time, which implies the cometary origin of most such particles. They are working with the statistical data to improve the predicted rates of erosion and vertical and lateral mixing of the regolith material, and the predicted cosmic-ray exposure ages of rocks.

Statistical analysis of lineament trends at the Apollo sites by G. G. Schaber and G. A. Swann define two predominant directions, northwest and northeast, and one secondary direction, north, at the Apollo 11 site. At the Apollo 12 site northwest, northeast, and north trends are best developed, but north-northwest and north-northeast sets are moderately distinct. These directions agree well with the five recognized "lunar grid" trends. It is probable that these small-scale lineaments, which are relatively young, have been constantly rejuvenated throughout a major part of lunar time in response to movements along joint planes in underlying bedrock. Such movements could have been generated by meteoritic impact, endogenetic volcanism, or tidal effects.

Field testing and experimentation

To test the application of telemetered seismic data to the solution of lunar structural problems, an array of six seismographs was deployed by Harold Masursky and J. M. Coakley along the Crescent fault, which bounds the northwestern front of the Cortez Mountains in central Nevada. The site provides a structural setting possibly analogous to the Appenine Front, one of the objectives on the Apollo 15 mission. During 20 days, 920 events were recorded; 168 of these were analyzed. One event appeared to originate within the network; its focal depth was 10.7 km and its magnitude was 0.9. The fault-plane solution indicated a vertical plane striking about N. 10° E. The surface trace of the fault indicates a dip of 60° NW., hence the fault must steepen downward if the solution is valid.

Detailed geologic mapping (1:6,000 scale) by D. P. Elston and G. R. Scott in the Horner Mountain quadrangle, Yavapai County, Ariz., has documented the stratigraphy in part of the Hackberry–Towel Peaks volcanic center. The sequence mapped to date includes more than 40 basalt flows; intervening deposits of sandstone; seven pumiceous tuff, crystal tuff, and tuff breccia flows; and an andesite and rhyolite flow. The varied stratigraphic and structural relations are locally well exposed, and the mapped area has been used for training the Apollo 16 prime and backup crews in geologic mapping and volcanic stratigraphy and structure. The flow sequence probably occupies the interval late Miocene to late Pliocene time; K-Ar age dating across the sequence is being carried out by E. H. McKee.

LUNAR AND PLANETARY INVESTIGATIONS

1:5,000,000-scale lunar geologic mapping

A 1:5,000,000-scale geologic map of the near side of the Moon by D. E. Wilhelms and J. F. McCauley[165] has been completed. It represents a summary of current understanding of the regional geology of the near side. In addition, work is in progress on five synoptic maps of the limb, far side, and polar regions which will complete mapping coverage of the entire Moon.

As a result of the lunar near-side mapping, 11 geologic provinces are now recognized; each is characterized by an inferred origin or a history that distinguishes it from the others. The provinces differ markedly in relative age and regional distribution pattern, which together lead to the following inferred geologic history: (1) An early period of intense bombardment that produced a surface saturated with craters in the 50- to 150-km size range. (2) A period of impact basin formation, probably overlapping with the early cratering during which ejecta blankets were emplaced around all of the multiring basins. (3) A period of terra volcanism which began during basin formation and continued at least until after the Imbrium event. Some of the younger plains, however, appear to postdate Orientale, the youngest of the large basins. (4) A main pulse of basaltic volcanism, of relatively short duration, which flooded the depressed parts of the near-side basins to varying levels. (5) Diminished volcanic activity, possibly of distinct composition, continuing up through the time of formation of the last ray craters. Contemporaneously with these last four major evolutionary episodes, impact cratering continued but probably at a progressively diminishing rate.

In addition, work has begun on a 1:5,000,000-scale map of the volcanic provinces of the near side. The work will include telescopic spectral measurements in four narrow-band passes in the visible wavelengths (0.35–1.10 μm). Results to date indicate that colorimetric variations over the lunar surface are directly related to the distribution of contiguous, chemically distinct volcanic units.

[165] Wilhelms, D. E., and McCauley, J. F., 1971, Geologic map of the near side of the Moon. U.S. Geol. Survey Misc. Geol. Inv. Map I-703. [In press]

Apollo site mapping

Premission geologic maps of the Apollo 14 landing site by R. E. Eggleton (r0949) and T. W. Offield indicated that most of the area is underlain by ejecta from the Imbrium Basin deposited in a series of north-south-trending ridges. Some elongate domes were interpreted as younger constructional volcanic features, but they do not occur in the immediate vicinity of the landing spot. The mapped area is covered with craters in various stages of destruction. Ejecta from a relatively young Copernican crater, informally named Cone Crater, covers much of the site and may compose most of the coherent rock samples returned to Earth.

Mars geologic mapping

Two prototype geologic maps were prepared from Mars Mariner 1969 imagery as a prelude to the systematic planetwide work planned on the data to be returned from Mariner 1971. The first is at a scale of 1:5,000,000 from Mariner 6, frame A-21, by J. F. McCauley. Four types of regional material and four crater units were mapped and arranged in stratigraphic order on the basis of superposition, and intersection relations or state of crater preservation. The second map by M. N. West from Mariner 6, frame B-20, is at a scale of 1:500,000; at this scale the Mars surface appears quite similar to that of the Moon. The work has demonstrated that Mars is geologically heterogeneous and amenable to the same stratigraphic approach applied to the Moon.

Morphology of Martian craters

Smoothed Mariner 4 depth–diameter measurements plotted and analyzed by R. J. Pike for 41 large Martian craters inflect at a crater diameter of 10 to 20 km in a manner similar to that found in lunar data. By analogy with the Moon, interpretations include variations in initial crater shape with increasing impact energy and postimpact modification. Apparent shallowing of large lunar craters with age indicates that postimpact changes affect the shape of lunar, and by inference, Martian crater depth–diameter distributions. A proposed model for emplacement and spreading of flat floors in large Martian and lunar craters suggests a time-dependent geologic sequence of events.

Geologic support for planetary missions

M. H. Carr, (r0759) in collaboration with a number of geologists, geochemists, geodesists, and cartographers, prepared a strategy for geologic exploration of the planets. The application and importance of stratigraphic principles to orderly exploration are stressed. The relative utility of flyby, orbital, and surface photography are discussed. Geophysical and geochemical remote-sensing techniques, and the question of priorities and the types of measurements important to planetary evolution are also treated.

CRATER INVESTIGATIONS

Pretoria Salt Pan, South Africa

The Pretoria Salt Pan is a crater about 1140 m in diameter located in the level expanse of the bushveld in Transvaal Province, South Africa. The origin of this geologically young (probably Quaternary) feature in an otherwise long quiescent terrain is a matter of debate; volcanism and impact have been proposed. A conclusive decision cannot be based on the gross structure as it is currently known. D. J. Milton found that, on a scale of decimeters, folds and thrust faults in the horizontally foliated granite indicate strong compressive stresses acting radially outward at low angles within the crater wall. Such structures in competent rocks are characteristic of impact craters but are unknown at volcanic craters.

The chief argument advanced for the volcanic hypothesis is the presence of carbonatite in the crater wall. Fission-track dating by D. J. Milton (r1348) and C. W. Naeser shows that the carbonatite is of Precambrian age, which clearly eliminates any possibility of genetic connection with the crater.

Explosive craters, Canada

A crater 75 m across and 5 m deep was produced in alluvium by detonation of a 500-ton sphere of TNT resting on the surface at the Defence Research Establishment, Suffield, Alberta, Canada. The morphology and structure of this crater, Dial Pack, were closely similar to that of the earlier Prairie Flat crater which has the same experimental conditions. In both experiments, well-developed central mounds with radial ridges extending toward the crater walls were formed; concentric ridges formed by uplifted anticlines were found on the outer part of the crater floor; a continuous overturned flap of ejecta overlies the crater rim, and part of the crater flanks and fragments of ejecta derived from the region below the TNT were fused. Detailed studies during excavation of the Dial Pack crater by D. J. Roddy showed that all the types of structural deformation found were also common to the Prairie Flat crater. Thus, the results from experiments producing craters in alluvium by large TNT spheres resting on the surface are reproducible.

The resulting experimental craters and their ejecta are analogous to both lunar craters and terrestrial craters. The topography and morphology of both the Dial Pack and Prairie Flat craters are strikingly similar to that of the Mare Orientale structure on the Moon. Blocky ejecta from a clay horizon at Dial Pack produces crater flanks topographically similar to those of small lunar craters in the 100- to 1,000-m class. Comparisons of the results from field studies of the Decaturville structure in Missouri by H. A. Pohn and T. W. Offield with the Dial Pack and Prairie Flat craters indicate that the Decaturville structure has been eroded to a level slightly below the zone of total disruption, that is, just below the floor of the true crater. Structural deformation at Flynn Creek, Tenn., is similar to that found for the Dial Pack and Prairie Flat craters.

Shock metamorphism of alluvium from large explosion craters

In the Prairie Flat and Dial Pack explosive cratering experiments conducted at the Defence Research Establishment, Suffield, Alberta, Canada, alluvial silty clays originally beneath the 500-ton TNT spheres were fused by shock compression and heating. Studies by D. J. Roddy of fused material recovered from the fallout revealed the presenee of vesicular glass spheres, rich in silica, with diameters up to 1 cm. This fused material was distributed as fallout on top of the ejecta and fallback. Comparison of X-ray fluorescence analyses of the fused material with analyses of samples from undeformed layers shows the silty clay material to be the parent material. Disequilibrium thermal fusion experiments and petrographic studies indicate that the fused material reached temperatures in excess of 1,100°C and probably greater than 1,500°C.

A broad spectrum of metamorphism resulting from shock is found in debris from these craters. Heating effects range from baking and slight oxidation to complete fusion with vesiculation. Deformation of quartz grains includes planar features, crushing, local isotropic regions, and complete fusion.

Comparison of the fused material from these experiments with some lunar spheres returned by Apollo 11 and 12 astronauts shows that they are similar. In both cases, large vesicular spheres have glass splatters on their surfaces. Additional parallels between the fused materials from these explosive craters and lunar glasses are being examined.

Meteor Crater, Ariz.

Examination of cuttings from 76 holes drilled through the ejecta of Meteor Crater, Ariz., to the contact between the Moenkopi Formation and Kaibab Limestone by D. J. Roddy, G. W. Colton, and J. M. Boyce has shown that inverted stratigraphy in the overturned flap can be found to a distance of 700 m from the rim. At a distance of 250 to 350 m from the rim and beyond, inverted stratigraphy is present, but local mixing of the layers occurs.

The ejecta thins outward. Sixty meters from the southwest rim, the overturned flap is 25 m thick. Three hundred and fifty meters from the rim the ejecta is, on the average, 10 m thick, and at 700 m it is discontinuous. Beyond this, isolated hummocky mounds of large ejecta blocks are found to at least 1,100 m.

Uplift of the original ground surface is as much as 40 m at the crater rim, and drilling shows it to be about 16 m at a distance of 30 m from the rim. Concentric folds are found around the crater to distances of 1,000 m.

The drill-hole data indicate that the surface around Meteor Crater at the time it was formed was similar to the present surface. Such a gently rolling surface is indicated by the thicknesses of Moenkopi Formation found in drill holes, which ranged between 3 and 11 m.

Drill cuttings were carefully collected at intervals of 0.25 to 0.7 m for use in future studies of shock metamorphism.

Craters used for astronaut training

Examination of the ejecta and walls of the crater Schooner, a 300-m-diameter crater at the Nevada Test Site, by H. J. Moore, D. J. Roddy, P. P. Orkild, and K. A. Sargent showed that it was ideally suited for astronaut training. Ejected rocks and debris are present in their normal stratigraphic sequence from the extremities of the ejecta to the crater rim. Exposures of ejecta on the upper crater walls reveal attenuated layers in an inverted stratigraphic sequence, while exposures on the lower crater walls show the stratigraphy in its normal sequence. During actual training exercises, the astronauts were able to collect samples from various units representing 64 m of section.

Geologic studies by D. J. Roddy and H. J. Moore of craters produced by explosives at the Black Mesa Crater field, Arizona, which is used for simulations of lunar traverses and astronaut training, have shown that the basic principles for collecting samples from underlying horizons using craters are well illustrated. The "drill hole" concept is shown by examination of ejecta from craters of progressively larger sizes. Ejecta from small craters 3 to 4 m in diameter are composed of material exclusively from the uppermost reddish-brown soil horizon. Ejecta from the next larger sizes of craters bring both the reddish-brown soil and underlying gravels to the surface. Craters with diameters larger than 12 m bring various units of the underlying Verde Formation to the surface. These craters also illustrate inversion of stratigraphy in the ejecta. Ejecta of coarse gravels are found superposed on ejecta of the reddish-brown soil at the rim and on the flanks of craters excavating both layers, while on the lower crater walls the stratigraphic relationships can be seen in their normal sequence. These relationships can also be seen in the largest craters where the inverted sequence of Verde Formation, coarse gravel, and soil is seen in the ejecta and the normal sequence of soil, coarse gravel, and Verde Formation is seen on the lower crater walls. As a result, various units in the Verde Formation can be placed in their proper stratigraphic sequence with careful observation.

During construction of the crater field, D. J. Roddy directed technical aerial stereophotography of the Black Mesa Crater field in cooperation with other Geological Survey investigators. The stereophotography was completed at different sun angles, at flight altitudes of 2,800, 1,000, 600, and 400 feet to assist in astronaut training and cratering studies. Ejecta blocks as small as 4 inches thick can be resolved on the low-altitude photos. High-speed blast photography from the air and ground shows the following: the air-ground shock waves, initial ejecta thrown from the crater at time of detonation, fallout patterns, development of secondary craters from ejecta, and base-surge clouds.

The crater field was reflown 2 months after formation at altitudes ranging from 200 to 2,600 feet to examine any modifications. The fine cover of dust from fallout and base surge was removed by wind and rain, thereby enhancing the ray patterns formed by ejecta.

Missile impact investigations

As a result of studies by G. V. Latham and W. G. McDonald (Lamont-Doherty Geological Observatory, Columbia University), H. J. Moore (USGS), and the Command at White Sands Missile Range, N. Mex.,[166] it was found that data on amplitudes of seismic signals generated by missile impacts provided a useful guide for predicting the amplitudes of initial seismic signals (P and S waves) produced by impacts on the lunar surface. The seismic data on missile impacts were used as a guide in selecting coordinates for the impacts of the lunar module of Apollo 12 and the Saturn IV-B stage of Apollo 13.

Mechanical properties of lunar surface materials estimated from secondary impact craters

H. J. Moore reports that bearing capacities estimated from secondary impact craters are generally the same order of magnitude as those reported by the Surveyor project. For 115 secondary impact craters and their corresponding blocks, dynamic strengths are estimated from: (1) the product of one-half the mass per unit area of the block and the square of the normal component of velocity by the crater depth, and (2) the ratio of the kinetic energy of the block to the volume of the secondary crater. Velocities of the blocks are calculated using an assumed ejection angle of 45°, and densities are taken as 2.7 g/cm^3. Dynamic strengths using the first procedure average 25.2×10^5 dynes/cm^2, and, using the second procedure, 19.2×10^5 dynes/cm^2. Assumed block densities near 3.2 g/cm^3 increase these strengths 20 percent. Dynamic strengths for each block generally exceed static strengths for lunar soils with angles of internal friction larger than 30°. Coefficients for terrestrial low-velocity impact equations for sand targets are larger than those calculated for lunar data. The coefficients for lunar data can be brought into better agreement by using ejection angles near 60° and accounting for lunar gravity.

[166] Latham, G. V., McDonald, W. G., and Moore, H. J., 1970, Missile impacts as sources of seismic energy on the Moon: Science, v. 168, no. 3928, p. 242–245.

Decaturville, Mo., structure

Detailed mapping and field checking by T. W. Offield and H. A. Pohn at the Decaturville, Mo., cryptoexplosion structure indicate a very complex sequence of deformation involving circumferential and radial folds and normal faults, and thrusts inward and outward. These phases of deformation are believed to have occurred penecontemporaneously and nearly instantaneously, accompanying the rise of a central dome and depression of a surrounding ring zone, following passage of a shock wave outward from the center of the circular structure. Shock pressures of about 50 kb are suggested by lamellae in quartz from rocks at least 1,200 feet below the probable focus of the event. Shock features and geometry of deformation indicate origin of the structure by impact. Fission-track determinations by C. W. Naeser for apatite in a tectonic inlier of Precambrian schist at the center of the structure suggest that the impact event occurred in Triassic time. Stratigraphic and geometric reconstructions of the disturbed rock section lead to the conclusion that the structure is nearly completely preserved rather than deeply eroded as was originally thought.

VOLCANIC INVESTIGATIONS

Galapagos Islands

Calderas in the Galapagos Islands being studied by K. A. Howard are similar to several circular structures on the Moon. Differentiated silicic rocks were erupted several times late in the history of Alcedo caldera. Together with morphologic evidence and a history of infrequent eruptions, this suggests that Alcedo is in a relatively advanced stage of caldera evolution. Collapse there has engulfed most of the steep upper dome that is characteristic of Galapagos volcanoes. Reconnaissance of all the Galapagos calderas indicates that small blocks within the calderas commonly subside independently of the main floor as in the Fernandina collapse in 1968. Sagging of the main floors in some calderas produces down-tilted slabs so that fault displacement is down to the outside. Except for silicic pumice eruptions at Alcedo, major explosions in Galapagos calderas have occurred only where lakes or high ground-water tables provided moisture.

Deep-seated inclusions

Detailed field analyses of xenolith suites in basaltic rocks of the Western United States are being made by H. G. Wilshire, N. J. Trask, and E. C. Schwarzman with the goal of better understanding deep lunar crustal or mantle rocks that may be obtained from ejecta deposits around large impact basins or as inclusions in basaltic rocks. Three main suites of xenoliths are common in the terrestrial basalts: (1) a suite characterized by chrome diopside and showing modal variations from olivine-rich to either diopside- or enstatite-rich rocks; (2) a suite characterized by black clinopyroxene and showing modal variations from olivine-rich to clinopyroxene-rich rocks; and (3) a suite of two-pyroxene granulites. Pyroxene-rich rocks in suites 1 and 2 form bands in olivine-rich rocks of those suites.

Hydrous minerals, amphibole and phlogopite, are commonly associated with the xenoliths and at two California localities form veins in the ultramafic rock. Textural relations show that the veins were emplaced after deformation and recrystallization of the peridotite. Microprobe data obtained by H. G. Wilshire (r1942), L. C. Calk, and E. C. Schwarzman show that originally titanium- and iron-poor amphibole has reacted with basalt to form kaersutite, the amphibole characteristically found with peridotite inclusions elsewhere in the world. Strontium data obtained by M. A. Lanphere support the conclusion, reached from study of textures, that the amphibole veining of mantle rock predates the basalt and is unrelated to it.

Basalts of the Columbia River Group

The great lateral extent and volume of the basalts of the Columbia River Group of middle Miocene–early Pliocene age make them comparable to the basaltic mare fills of the large circular impact basins on the Moon. The two broad magmatic units recognized earlier by Waters[167] are also detectable by relatively fast rock chemical analyses carried out under the direction of M. J. Grolier. A large number of rapid analyses makes possible a refinement of the original breakdown and may lead to the identification of microcycles within the broad magmatic units already defined. Abrupt variations in the percentages of oxides from one basalt layer to the next suggest that lava flows exposed in one section may originate at different, perhaps widely different, magmatic reservoirs and vents.

COSMIC CHEMISTRY AND PETROLOGY

Ivory Coast tektites

Frank Cuttitta, M. K. Carron, and C. S. Annell completed physical property and elemental studies on selected Ivory Coast tektites and Bosumtwi Crater glasses. They show marked similarities between their elemental abundances and correlations. In light of the foregoing similarities and the completely dissimilar nature of the Apollo 11 and 12 lunar maria rocks and soils, a lunar origin for the Ivory Coast tektites does not seem probable. The evidence strongly indicates that the Ivory Coast tektites are the fusion products and ejecta resulting from a meteoritic impact event at the Bosumtwi Crater site.

Magnetic properties of microtektites

F. E. Senftle, C. C. Alexander (USGS), and A. N. Thorpe (r0806) (Howard University) have measured the magnetic

[167] Waters, A. C., 1961, Stratigraphic and lithologic variations in the Columbia River basalt: Am. Jour. Sci., v. 259, p. 583–611.

susceptibility, magnetization, and Curie constants for 17 normal and 11 bottle-green microtektites found in deep-sea sediment cores.[168] Unlike tektites, all the normal microtektite specimens have a significant intensity of magnetization, which is ascribed to a ferromagnetic iron oxide film on the surface of the microtektites which can be removed by acid leaching. The ferrous iron content calculated from the Curie constant compares with the total iron determined with the electron probe. Within experimental errors there was a one-to-one correspondence between the calculated ferrous iron and the measured total iron, a property similar to that of tektite glass. The bottle-green microtektites showed properties similar to those of the normal variety before leaching. Although the leaching process did not affect the bulk iron content of the normal microtektite glass, it was possible to remove all iron from the bottle-green glass. In this respect the bottle-green microtektites are quite different from normal microtektites or tektites. The solubility suggests that the bottle-green specimens may have partially reacted with the sea water, thus altering their original magnetic properties.

Allende meteorite

I. A. Breger, J. C. Chandler, and Peter Zubovic have isolated "organic matter" from the Allende meteorite which proved to be amorphous carbon. X-ray diffraction analysis of a mineral separate has also indicated the possible presence of a chromium spinel.

Mineral exploration by nuclear techniques

Results of investigations by F. E. Senftle,[169, 170] R. M. Moxham, and A. B. Tanner (P. F. Wiggins and others, r1399, r1400; A. G. Evans and others, r1401; J. I. Trombka and others, r1408) with the use of a californium-252 neutron source for in situ mineral exploration have demonstrated the feasibility of prompt-capture gamma measurements for the detection and analysis of certain elements, particularly nickel, copper, and titanium. Marine and space applications, particularly for the analysis of the surface of Mars and Venus, also appear promising.

[168] Senftle, F. E., Thorpe, A. N., and Sullivan, Samuel, 1969, Magnetic properties of microtektites: Jour. Geophys. Research, v. 74, no. 27, p 6825–6833.

[169] Duffey, D., El-Kady, A., and Senftle, F. E., 1970, Analytical sensitivities and energies of thermal-neutron-capture gamma rays: Jour. Nuclear Instruments and Methods, v. 80, p. 149–171.

[170] Senftle, F. E., Philbin, P. W., and Sarigianis, Perry, 1970, Use of ^{252}Cf for mineral exploration—Comparison with accelerators for in situ neutron activation of silver: Isotopes and Radiation Technology, v. 7, p. 411–418.

INVESTIGATIONS OF APOLLO LUNAR SAMPLES

Petrology of lunar rocks

Edwin Roedder (USGS) and Paul Weiblen (University of Minnesota) have found in the Apollo 12 rocks the same two unusual features that they discovered earlier in Apollo 11 rocks—epitaxially oriented daughter minerals in melt inclusions in early olivine, and late-stage silicate immiscibility. More important, however, they found both features, previously unnoticed, plainly visible in samples from three Hawaiian basalt lava lakes, and they also found the immiscibility in basalts from Modoc, Calif., Disko, Greenland, and in Precambrian volcanic rocks from Minnesota. Both observations have important implications with regard to the cooling history and differentiation trends in lunar and terrestrial basalts.

The early silicate melt inclusions and their daughter minerals provide excellent material for experimental laboratory determinations of the crystallization temperatures and trends, using the host olivine crystal as a convenient "bottle", and permit clear distinction between some phenocrysts and xenocrysts. The late-stage silicate liquid immiscibility may be of considerable petrologic importance. The residual liquid between the crystals of the solidifying basalts was found to have split into two immiscible melts grossly different in composition (potassic granite and iron-rich pyroxenite). Similar separation on a large scale may well have occurred during the formation of the early crust of the Earth or Moon.

Petrographic and microprobe studies by O. B. James indicate that lunar sample 12013 is a thermally metamorphosed microbreccia. The sample is heterogeneous, with three dominant rock types: (1) gray fragment aggregate, (2) dark-gray fragment aggregate, and (3) light-gray felsite. Mineralogically, types 1 and 2 consist dominantly of pyroxene and plagioclase, whereas type 3 is composed almost entirely of potassium feldspar and quartz. Rock types 1 and 2 contain different fragment suites and different types of matrices indicating that they initially represented two different fragmental rocks. Most of sample 12013 is a mottled mixture of types 1 and 3; type 2 occurs as large patches within this mottled rock. The textures and gross structures of the rock and comparisons with unmetamorphosed lunar breccias suggest the following interpretation of the origin of the sample. Gray aggregate (1) consists largely of fallout impact debris; it represents the groundmass material of the breccia. Dark-gray aggregate (2) was included in this breccia as aggregates of fragments bound together by a molten or glassy matrix. Felsite (3) was incorporated as fragments of glass or irregular droplets of melt. Heating during or after aggregation produced metamorphic mineral reactions and textures.

The petrology of unshocked and shocked Apollo 11 and 12 microbreccias has been studied by E. C. T. Chao, J. A.

Boreman, and G. A. Desborough.[171] Apollo 11 and 12 microbreccias consist of poorly consolidated to moderately well consolidated particulate material similar to that of the fines of the regolith where they were collected. The Apollo 11 microbreccias contain fragments of crystalline rocks and minerals from ilmenite basalts, fragments of glassy aggregates, and particles of homogeneous and heterogeneous glass. Fragments of anorthositic rocks and old microbreccias are also present. The bulk of the material of particle size less than 25μm consists of mineral powder variously coated with glass.

In Apollo 12 microbreccias, olivine-pigeonite basalts are the principal lithic types. Ilmenite content is lower than in the Apollo 11 samples, and transparent mineral fragments dominate over rock fragments. The Apollo 12 microbreccias also contain abundant maroon irregular-shaped glassy particles which are relatively high in alkalies and phosphorus; very few of the glass particles are spherules. Anorthositic rocks and fragments of plagioclase-rich rock containing orthopyroxene are also present.

Both unshocked and shocked microbreccias are present among the Apollo 11 and 12 samples. All large microbreccia samples studied are unshocked and are characterized by a porous texture. They break along grain boundaries. Shocked microbreccias are characterized by a compact texture and by the presence of a set of subparallel to parallel, discontinuous tension microfractures; these microbreccias break across grains. In addition, most phases have extensive microfractures, and most ilmenite fragments show lamellar twinning which is interpreted to be the result of shock. Similar shock features are observed within the substrate immediately beneath small impact craters in unshocked microbreccias.

The presence of several generations of breccias and lithic and glass particles of diverse source areas, and the general lack of evidence of welding, suggest that most microbreccias are consolidated by cold compaction of fallout ejecta produced at different times by different small impact events in the regolith.

Motoaki Sato (r2518) and R. T. Helz studied the oxygen fugacity values of three Apollo 12 lunar basalts (12009, 12022, 12053). Although accurate determination of the oxygen fugacity values was found to be difficult even with the solid electrolyte sensor method because of extremely low ferric to ferrous ratios of lunar basalts and the limited quantity of the samples, it was found that the degree of reduction of the lunar basalts is beyond the limit that can be reached by vacuum pumping of oxygen from the lunar magmas. On the basis of much higher vapor pressure and availability of sulfur, they inferred that the ultimate reduction of the lunar magma to the extent of precipitating metallic iron is probably achieved by the vacuum degassing of elementary sulfur.

[171] Chao, E. C. T., Boreman, J. A., and Desborough, G. A., 1971, The petrology of unshocked and shocked Apollo 11 and 12 microbreccias: Apollo 12 Lunar Sci. Conf. Proc., Massachusetts Inst. Technology Press, Cambridge, Mass. [In press]

Mineralogy and crystallography of lunar rocks

D. B. Stewart, D. E. Appleman, J. S. Huebner, Eric Dowty, and J. R. Clark[172] have made extensive crystallographic and chemical studies on plagioclases from returned Apollo 11 and 12 lunar rocks 10003, 10020, 10047, 10050, 10057, 10071, 10072, 12021, 12038, 12040, and 12051. They have shown that there is little variation in plagioclases within a given rock. Techniques were developed so that the same single crystal, as small as 18 μm on an edge, could be studied by X-ray diffraction, electron diffraction, electron microscopy, and electron microprobe analysis. The total range of composition in all rocks was approximately An_{73} to An_{92}. All plagioclases showed sharp *a* reflections; *b* reflections ranged from sharp to slightly diffuse in the least calcic crystals. All but the least calcic showed very weak and diffuse *c* reflections. Mössbauer studies found Fe^{+2} in both tetrahedral and large-cation sites. Cell parameters obtained by accurate powder-diffraction measurements can be correlated with composition. The transition from body-centered to primitive (anorthite) geometry is at approximately the same composition as in terrestrial plagioclases. Domains corresponding to the broadened *c* reflections were observed. Crystal-structure refinements are in progress.

Malcolm Ross, J. S. Huebner, and Eric Dowty[173] have found that pyroxene crystals in lunar rock 12021 contain exsolution lamellae of two types: pigeonite lamellae in an augite host, and vice versa. Heating experiments under conditions of controlled oxidation states established that the two-phase crystals of lowest iron content became homogenized to single pyroxene phases at temperatures between 1,140° and 1,176°C, suggesting that the crystals themselves formed at higher temperatures. On the other hand, some iron-rich augite crystals were homogenized at temperatures of about 1,025°C, suggesting that the solvus for yet more iron-rich compositions may be at temperatures below the solidus. Heating of low-calcium pigeonites with low to intermediate iron contents produced orthorhombic hypersthene at temperatures above 1,160°C and finally the assemblage hypersthene-augite-liquid. These experiments suggest that crystallization of liquids rich in MgO may have precipitated hypersthene as the first pyroxene phase but that it later reacted completely to form pigeonite so that there is no trace of hypersthene in the rocks. Continued cooling led to coprecipitation of pigeonite and augite and finally to the exsolution lamellae observed in the single crystals. Some

[172] Appleman, D. E., Nissen, H. U., Stewart, D. B., Clark, J. R., Dowty, Eric, and Huebner, J. S., 1971, Crystallographic studies of lunar plagioclases, tridymite, and cristobalite: Apollo 12 Lunar Sci. Conf. Proc., Massachusetts Inst. Technology Press, Cambridge, Mass. [In press]

[173] Ross, Malcolm, Huebner, J. S., and Dowty, Eric, 1970, Melting and sub-solidus phase relations of augite and pigeonite from lunar rock 12021: Rept. to Natl. Aeronautics and Space Adm., distributed at Apollo 12 Lunar Sci. Conf., Houston, Tex., Jan. 11–14, 1971.

aspects of the phase relations are similar to those found in a variety of terrestrial igneous rocks.

J. R. Clark, Malcolm Ross, and D. E. Appleman[174] have investigated a lunar pigeonite crystal from rock 10003, 38. It has broadened class *b* reflections ($h + k = 2n + 1$) similar to those observed by Morimoto and Tokonami[175] for a pigeonite from Isle of Mull, Scotland. The broadening suggests the presence of a domain structure with domains about 100 A in size. Least-squares refinement of the class *b* diffraction data reveals that the structure of the principal domains in the lunar pigeonite is close to that of a clinohypersthene with composition approximately $Mg_{0.54}Fe_{0.46}SiO_3$; the *M*2 site is six coordinated, and the domains are assumed to have very little calcium (0.04 atom per given formula unit, at most). The boundary regions between the domains are assumed to be calcium rich, as suggested by Morimoto and Tokonami. Least-squares refinement of all the data or of the class *a* data alone ($h + k = 2n$) produces a "statistical" structure, similar to that described by Morimoto and Güven[176] for the Mull pigeonite. This statistical structure is considered to be an artifact produced by using normal data handling procedures in an abnormal situation. The most plausible explanation for its appearance is the presence of the antiphase domains postulated by Morimoto and Tokonami.

Crystals of tridymite were discovered in rock 12021, and their structure is being investigated by D. E. Appleman and J. R. Clark. Comparison of single-crystal diffraction patterns with those obtained by W. A. Dollase (written commun., 1971) for tridymite from the Steinbach meteorite shows that both tridymites have very similar large twinned monoclinic cells. The lunar tridymite has a pronounced orthorhombic subcell with space group $C\ 222_1$, $a = 8.65 \pm 0.02$ A, $b = 5.01 \pm 0.01$ A, $c = 8.21 \pm 0.02$ A, similar to the orthorhombic high tridymite to which the Steinbach material transforms reversibly when heated above 180°C. The subcell yields a highly disordered structure virtually identical with that found by Dollase[177] for the Steinbach tridymite at 220°C. The true structure of both lunar and meteoritic tridymite at room temperature is apparently ordered, which accounts for the large cell and reduced symmetry.

Fine single crystals of troilite (the only sulfide mineral found in lunar samples returned by the Apollo 11 and 12 missions) were found in vugs in coarse-grained ilmenite-gabbro-type rock (specimen 10050). One of these crystals was used by H. T. Evans, Jr. (r0500), to carry out a complete structure analysis and refinement, using three-dimensional intensity data measured with the Picker automatic single-crystal diffractometer.[178] The approximate structure proposed by Bertaut in 1956, based on the NiAs-type structure, was confirmed. Fe-S bond lengths in the distorted FeS_6 octahedron were determined with standard deviations of 0.003 A, and were found to be: 2.359, 2.379, 2.415, 2.504, 2.565, and 2.722 A.

Chemical analyses of lunar materials

One Apollo 12 basalt, 12038, was analyzed by L. C. Peck and V. C. Smith with the classical wet-chemical method. The analysis in weight percent is as follows: SiO_2 47.13, Al_2O_3 13.03, FeO 17.73, MgO 6.60, CaO 11.43, Na_2O 0.69, K_2O 0.06, TiO_2 3.28, MnO 0.25, and P_2O_5 0.14.

Age determination and isotopic studies

One of the most important recent results is that the age of the Moon (starting time accretion and development of Moon's surface) was determined to be 4.65 b.y. by uranium-thorium-lead systematics studies of Apollo 11 and 12 samples by Mitsunobu Tatsumoto and R. J. Knight.

The data in the U-Th-Pb system on crystalline rocks returned from the Apollo missions confirm the great antiquity and extreme depletion of common lead of lunar rocks in the maria. Unlike the rocks analyzed from Apollo 11, those from Apollo 12 do not define a good Pb-Pb isochron, although six of eight rocks lie close to a 3.9–4.0-b.y. isochron as compared to a well-defined 4.2-b.y. isochron for Apollo 11 rocks and a 4.37-b.y. isochron for the unusual rock 12013. These Pb-Pb isochron ages are about 10 percent older than those obtained by the Rb-Sr mineral isochron and $^{39}Ar/^{40}Ar$ whole-rock ages.

It is surprising that the degree of agreement between U-Th-Pb methods and other dating techniques is much better on the soils and breccias of complex origin than on the rocks. In general the U-Th-Pb data indicate that the soils were derived from source material about 4.5 b.y. in age with differentiation of U relative to Pb at times equal to or younger than 4.0 b.y.; however, U-Th-Pb data on Apollo 12 soils and breccia indicate alteration in U/Pb at times much younger than 3.0 b.y.

Thirteen samples of lunar rock and soil and three separated minerals returned by the Apollo 12 mission from the Ocean of Storms were analyzed by combined semimicro, chemical, and X-ray fluorescence methods by Frank Cuttitta, H. J. Rose, Jr., C. S. Annell, M. K. Carron, R. P. Christian, E. J. Dwornik, L. P. Greenland, A. W. Helz, and D. T. Ligon, Jr.[179] As noted in Apollo 11 samples, content of Al_2O_3, Na_2O, K_2O, and

[174] Clark, J. R., Ross, Malcolm, and Appleman, D. E., 1971, Crystal chemistry of a lunar pigeonite: Am. Mineralogist, v. 56. [In press]

[175] Morimoto, Nobuo, and Tokonami, Masayasu, 1969, Domain structure of pigeonite and clinoenstatite: Am. Mineralogist, v. 54, p. 725–740.

[176] Morimoto, Nobuo, and Güven, Necip, 1970, Refinement of the crystal structure of pigeonite: Am. Mineralogist, v. 55, p. 1195–1209.

[177] Dollase, W. A., 1967, The crystal structure at 220°C of orthorhombic high tridymite from the Steinbach meteorite: Acta Cryst., v. 23, p. 617–623.

[178] Evans, H. T., Jr., 1970, Lunar troilite—Crystallography: Science, v. 167, p. 621–623.

[179] Cuttitta, Frank, Rose, H. J., Jr., Annell, C. S., Carron, M. K., Christian, R. P., Dwornik, E. J., Greenland, L. P., Helz, A. W., and Ligon, D. T., Jr., 1971, Elemental composition of some Apollo 12 lunar rocks and soils, *in* 1971 Apollo 12 Lunar Sci. Conf. Proc.: Geochim. et Cosmochim. Acta, Suppl. 1. [In press]

P_2O_5 is higher in the lunar soils, while content of FeO and MnO is notably higher in the igneous rocks. Whereas the mineralogical components are similar for rocks from both sites, Apollo 12 samples appear to have more olivine and less ilmenite, and this variation accounts for the differences in chemical composition when the results are compared with Apollo 11. Samples from both sites have higher refractory-element contents and lower volatile-element concentrations than comparable terrestrial rocks. (See related studies, p. C179–C181, C182–C184).

Eight glassy spherules showing a variation in color from deep brown to light green and ranging in size from 0.3 to 0.6 mm were selected from Apollo 12 soil 12070 for magnetic susceptibility and other physical-property measurements and for determination of TiO_2 and FeO content by Samuel Sullivan (Howard University), A. N. Thorpe, C. C. Alexander, F. E. Senftle, and E. J. Dwornik.[180] Petrographic examination of several of the polished transected surfaces revealed many unusual features that made meaningful interpretation of magnetic properties and electron probe analysis more difficult.

In several of the glassy spherules, spherical inclusions with high iron content were noted, and in another, glassy matrix euhedral crystals of what is probably native iron 1 to 2 μm in size were noted. Analyses for SiO_2, CaO, K_2O, MgO, Al_2O_3, NiO, MnO, and Na_2O were also performed.

The analysis of Apollo 12 materials for the content and isotopic composition of hydrogen and carbon was completed by Irving Friedman, J. R. O'Neil, J. D. Gleason, and K. G. Hardcastle. The carbon results are in agreement with their results on Apollo 11. The dust contains CO_2 and CO as well as fixed carbon. The various carbon species differ in C^{13} abundance, the CO_2–CO having a δC^{13} of approximately +3°/oo PDB[180a], whereas the remaining carbon has a δC^{13} of approximately -25°/oo. The total δC^{13} in the dusts varies in the samples from -15°/oo to -23°/oo. Samples of lunar basalts containing 8 to 34 ppm carbon had a δC^{13} of -25°/oo.

The amount and isotopic composition of hydrogen and water in both the dust and crystalline rocks were also determined. The dust contains large quantities of solar-wind hydrogen, which is present both as hydrogen and as water. This solar-wind hydrogen is depleted in deuterium, and there is still some uncertainty as to the extent of depletion, since there was difficulty in removing earth contamination from the samples. An analysis of the interior of a large crystalline rock showed that it contains about 6 ppm hydrogen, bound both as hydrogen and possibly as water. This hydrogen appears to be enriched in deuterium compared to earth materials. The source of this enriched hydrogen is still unknown, but contribution of deuterium from spallation processes might account for it.

[180] Sullivan, Samuel, Thorpe, A. N., Alexander, C. C., Senftle, F. E., and Dwornik, E. J., 1971, Magnetic properties of individual glass fragments and microscopic spherules, Apollo 11 and Apollo 12 lunar samples, *in* 1971 Apollo 12 Lunar Sci. Conf. Proc.: Geochim. et Cosmochim. Acta, Suppl. 1. [In press]

[180a] PDB, Pee Dee Belemnite standard.

Physical properties of lunar rocks

The magnetic properties of two samples of crystalline rock returned from the Moon by the Apollo 12 expedition were investigated by C. S. Grommé and R. R. Doell. The Curie temperatures are close to 785°C, and the magnetization curves are nearly straight up to field strengths of 4,000 to 6,000 Oe, indicating that the ferromagnetic material in these rocks, in the form of small spheres, is metallic iron containing a few percent of cobalt. Remanent magnetizations on the order of 10^{-5} emu/g were measured in the samples, but this magnetization was not stable after heating to successive temperatures of 200°, 400°, and 600°C, nor could equivalent thermoremanent magnetizations be produced in the samples. Hence these lunar samples do not possess an incontrovertible record of a possible ancient lunar magnetic field.

Lunar glasses and lunar fines

Lunar glasses of impact origin are significant components of the fines and microbreccias collected by the Apollo 11 and 12 missions. Occurrences, relative abundance, optical properties, and chemical composition were studied extensively by E. C. T. Chao (r1333), J. A. Boreman, J. A. Minkin, O. B. James, and G. A. Desborough in order to assess the importance of lunar glasses with respect to the bulk composition, apparent age, and origin of the regolith. Only a few of the glasses are homogeneous. They occur as splash-form particles or as angular fragments in fine fines and breccias. The homogeneous glasses show a wide range of compositions, but these compositions tend to group; it is likely that they represent the composition of the parent materials. Heterogeneous impact glasses are characterized by pronounced schlieren, abundant vesicles, and inclusions of mineral fragments and small nickel-iron particles. Their chemical compositions vary, but the range is restricted. They are probably derived by impact fusion of breccias or fines. Analyses of heterogeneous crater glass lining small pit craters in a crystalline rock and in a microbreccia show that the composition of the crater glass is highly dependent on the crater size relative to the crystal or fragment size of the substrate; volatilization of major elements during fusion is negligible or minor. Mixing calculations show that the bulk chemical composition of the Apollo 11 breccias and fine fines can be obtained by combining 66 to 82 wt percent ilmenite basalt, 17 to 28 percent plagioclase-rich glass, and 1.5 to 6 percent olivine-rich glass; the latter two estimates represent minimum amounts of added material. Because of this large contribution of impact glasses of diverse parent materials to the breccias and fine fines, it is likely that the glasses play a critical role in the explanation of the isotopic concentrations of Rb, Sr, U, Th, and Pb that determine the apparent model age of the lunar regolith.

The magnetic properties of eight glass spherules (0.02–1.5 mg) from the bulk lunar fines (samples 10084, 86-2) of Apollo 11 have been investigated by F. E. Senftle, A. N. Thorpe, and C. C. Alexander. All the specimens showed strong paramagnetism due to Fe^{2+}, and most of the specimens also showed soft and hard ferromagnetic components. The iron in the form of spheres is the source of the hard magnetic component, and the amount present is calculated from the high field saturation magnetization and from the temperature-independent susceptibility at low and high temperatures. The same amount of iron (less than 1 percent) can be determined by all three methods, confirming that the hard component is due to nickel-iron or iron spheres in the glass. The soft component is due to odd-shaped fragmental iron or ferromagnetic minerals. No significant superparamagnetism was observed.

The mineralogy, petrography, and grain-size distribution of various samples of Apollo 11 and 12 fines were studied by G. A. Sellers, C. C. Woo, and M. L. Bird. In general, the lunar fines (less than 1 mm in diameter) represent petrographically the larger rocks returned with them, although the fines show a broader diversity of rock types. The fines show a higher proportion of exotic materials than do the hand specimens picked up at the same site.

The surface samples from Apollo 11 and from Apollo 12 have very similar grain-size distributions. This implies that the process or processes acting upon and producing the surface materials of the lunar maria are similar even for regions that are far apart. The surface samples also contain larger proportions of magnetic glass than do regolith samples taken from below the surface layer. The magnetism of the glass is primarily due to the meteoritic iron included within it. The accumulation of the magnetic glass is apparently correlated with the length of time the surface layer has been exposed to impacts by small meteorites.

Unit VI, the coarse layer, from the Apollo 12 double core was studied by these investigators. It may represent the primary impact debris of a rather restricted rock type from the bedrock underlying the Apollo 12 landing site. Although the evidence is tenuous, this debris may have been derived from one of the later impacts at the site, the one that produced the Bench Crater. Most of the lower units in the core appear to be a mixture of debris that was thrown into the core site by smaller impacts that merely redistributed regolith material.

Impact metamorphism of lunar samples

X-ray precession and Laue techniques have been utilized by J. A. Minkin and E. C. T. Chao,[181] to study undeformed, tectonically deformed, and experimentally deformed single crystals of terrestrial ilmenite, and undeformed and weakly and moderately shocked lunar ilmenite single crystals. Twinning in tectonically deformed crystals occurs on [10$\bar{1}$2], a crystal statically deformed in the laboratory is twinned on [10$\bar{1}$1], and of three shocked crystals examined one is twinned only on [10$\bar{1}$1] and two are twinned on [0001] and [10$\bar{1}$1]. No change in cell dimensions with shock is detected. Analysis of the asterism observed for the various deformed samples suggests that the lattice distortion is the simplest and that strain is equal in all directions in the tectonically deformed crystal. The yielding of the lattice is more complex in the experimentally deformed crystal and most complex of all in the shocked crystals, in which the degree of deformation is crystallographically specific. The greatest lattice distortion in the shocked crystals is shown in the reciprocal lattice net perpendicular to an *a* axis, and the least in the *hk*0 net (normal to the *c* axis).

Preliminary examination of Apollo 14 samples

E. D. Jackson, H. G. Wilshire, and N. J. Trask, Jr., participated in the preliminary examination of Apollo 14 samples at the Lunar Receiving Laboratory, Manned Spacecraft Center, NASA, Houston, Tex. More than 90 lb of lunar samples were returned by Apollo 14. Most of them are microbreccias. Only two samples (14053 and 14310) weighing more than 200 g are crystalline volcanic rocks.

[181] Minkin, J. A., and Chao, E. C. T., 1971, Single crystal X-ray investigation of deformation in terrestrial and lunar ilmenite: Apollo 12 Lunar Sci. Conf. Proc., Massachusetts Inst. Technology Press, Cambridge, Mass. [In press]

REMOTE SENSING AND ADVANCED TECHNIQUES

EARTH RESOURCES OBSERVATION SYSTEMS (EROS) PROGRAM

The Earth Resources Observation Systems (EROS) Program, administered by the Geological Survey for the U.S. Department of the Interior, in cooperation with the National Aeronautics and Space Administration (NASA), continued in 1971 to investigate applications of remote sensing to earth-resources inventory and management. The approaching launch of the first Earth Resources Technology Satellite (ERTS-A) in March 1972 has established a schedule of operational requirements for data handling and information management that is now superimposed on continuing applications development. The EROS data center at Sioux Falls, S. Dak., is in the architectural and engineering design stage. Temporary facilities are being set up to provide for assembly and pre-ERTS preparation and testing of equipment so that, at the time of launch, the center will be ready to fulfill its purposes: to provide space-collected data to Federal and non-Federal government users and to all other groups that can make beneficial use of it; to prepare small-scale thematic maps from the space data for use by resource agencies; and to provide facilities for the use of some analytical and interpretive equipment, together with advice on methods of data use.

Work on experiment proposals for ERTS-A and Skylab (the manned earth-orbiting laboratory also to be launched by NASA in 1972) has commanded much time and attention. In addition to preparation of proposals by individual Federal bureaus, joint proposals by several bureaus and by bureaus and nongovernmental groups have been developed. More than 60 proposals have been submitted on various aspects of resources inventories and on environmental quality assessments. All State Geologists were notified by the EROS Program Director of the ERTS experiment opportunity and were offered assistance if they wished to participate.

A multidiscipline approach to ERTS data applications has been facilitated by the establishment of regional ecological test sites. Thus far formal organizations include the Arizona Regional Ecological Test Site (ARETS) and the Central Atlantic Regional Ecological Test Site (CARETS). The purpose of the regional ecological test site is to concentrate investigations and experiments in diverse regional environments so that the collection and dissemination of data can be handled more efficiently and so that the collaboration of several disciplines, both as investigators and as users, can enhance the final results.

A supplemental study, conducted for the U.S. Bureaus of Indian Affairs, Land Management, and Reclamation by the Raytheon Co., Autometric Operation,[182] evaluated the accuracy of their previous interpretation of Apollo 9 photography and high-altitude airborne photography of eastern Arizona. The study, based on a brief field check, showed that had the original interpretations been combined with detailed information from ground sources, they would have resulted in significant information gain. The availability of frequent repetitive coverage over areas of interest would also have greatly increased the utility of the Apollo photography.

The Bureau of Reclamation continued its investigation of wetlands in the Columbia River basin of Washington, under the leadership of H. H. Ham, to determine the effect of irrigation on ground-water level and salt accummulation. When the water level rises and salt content increases as the result of irrigation so as to cause plant stress, drainage must be introduced. The study is trying to determine whether this plant stress can be identified by use of multispectral techniques. Thus far multispectral imagery has been processed by the University of Michigan in an effort to identify those areas developing the adverse reactions described. Evaluation by the Bureau of the report prepared includes further field investigation, which is now in progress.

Numerous projects were initiated by various bureaus of the Department of the Interior under funding, technical, and administrative support of the EROS Program. Boeing Computer Services, Inc., is creating a prototype operational Natural Resources Information System for the Bureau of Indian Affairs and the Bureau of Land Management based on the following system requirements: compatibility with existing management information systems within the Bureaus; capability to use data derived from remote sensors and ground sources; accommodation of data on variable-size areal elements to permit coarse analysis of large areas or detailed analysis of small areas; capability to analyze and interpret imagery using state-of-the-art techniques, such as optical scanning and digitizing, and enhancement of multispectral data; retrieval of information on a geographic grid system; and capability to display retrieved information graphically as well as in tabular form.

[182] Raytheon Company, Autometric Operation, 1970, Ground observations and utility evaluations of space and high-altitude photography, eastern Arizona: U.S. Dept. Interior, EROS Program, 23 p.

Investigations by J. F. Daniel[183] (p. C192–C195) on the development of a ground data sensor network utilizing the data relay system on ERTS-A have defined two goals: that the ground data be available concurrently with the imagery obtained by the satellite in order to provide an aid in interpretation of that imagery, and that the system test the feasibility of using real-time data relayed by the satellite as an aid in resource and river basin management.

The Bureau of Mines, as part of a continuing program to determine the applications of repetitive synoptic photography and other sensors to monitoring strip mining activities to determine their effect on semiarid environments and to facilitate plans for restoration after mining is concluded, has initiated the Black Mesa coal mine project under W. C. Henkes. Aerial photography was obtained in September 1970 over the 100 sq mi leased by the Peabody Coal Co. for a strip coal mine on Black Mesa within the Navajo and Hopi Indian Reservations north of Winslow, Ariz. Interpretation of this photography has provided the before-mining ecological conditions for monitoring, among other things, changes in vegetation vitality, land use, water supply, and erosion, that might result from the strip mining operations.

The Bureau of Mines has awarded an EROS-funded contract to the Aerojet-General Corp. to investigate the use of passive microwaves to identify areas of potential mine subsidence. The study is being conducted in the vicinity of Rock Springs, Wyo. The work is based on the premise that where soil moisture content is variable, the more stable areas will retain moisture longer than will those where the subsurface is disturbed. Preliminary indications are that moderate success can be achieved in defining these areas.

The Bureau of Mines, in a project under Brian Harney, is studying the feasibility of detecting and monitoring air pollution from mineral processing and utilization of mineral fuels with airborne and spaceborne sensors. The study is being conducted at a powerplant complex in southwestern Pennsylvania that incorporates coal operation and the use of very tall stacks for more efficient dispersal of stack effluents. An air-quality monitoring system and test plots to determine the effects of stack emissions on vegetation already exist and are providing the ground truth against which the remotely sensed data is measured. The study includes the development of interpretive techniques for analyzing aerial and orbital imagery in terms of air pollution and its environmental effect and the development of an expanded model of utilization for use in operational programs.

The Bureau of Indian Affairs has obtained thermal imagery of the Mount Baldy area in the Fort Apache Reservation of Arizona in an effort to control an infestation of Englemann spruce beetles. Effective control measures require the elimination of infested trees during the first year of the beetle's life cycle. Since the foliage of an infested tree does not exhibit any discoloration during this first year, an attempt is being made, under the direction of A. M. Woll, to detect by the use of thermal imagery the sick trees, which are known to have temperatures 2° to 4°C higher than normal. Interpretation of the thermal data has been done by the Arizona Operations of the Bell Aerospace Co. Preliminary findings indicate that the thermal data collected in November under adverse weather conditions are not of an acceptable quality, and recommendation has been made for a new survey to be accomplished under conditions that will offer the greatest potential for the collection of good thermal data.

The Bureau of Indian Affairs has an EROS-funded contract with Amuedo and Ivey to provide to the Papago tribe a report showing potential mineral areas within their reservation in southeastern Arizona by comparing and correlating space imagery with high-resolution imagery and aeromagnetic data. The mineralization target areas are based on intrusive masses, zones of hydrothermal alteration, and aeromagnetic lineaments. Some preliminary results indicate that (1) high-altitude aircraft photography in conjunction with some reconnaissance geologic mapping could be used to produce a greatly improved geologic map at a much larger scale than the original map; (2) only some zones of alteration of large-volume disseminated-type deposits could be identified on high-altitude photography; all others were too small to be identified on either high-altitude or satellite photography; and (3) high-altitude photography was better in all respects than the satellite photography for geologic interpretation. This result was to be expected because of the size of the study area and because of the scale required to perform the study. Satellite photography is best used to identify regional target areas, which in this case had already been done.

The South Dakota School of Mines, under contract to the EROS Program, is conducting a statistical evaluation of the geologic information content of photography at low, intermediate, and high aircraft altitudes as well as orbital altitudes. They are employing the method known as edge counting along lines across sample images to determine how often tones change in correspondence with different geologic features. Preliminary results show that there is a consistent range of edges per inch in three Apollo photographs studied by two different students. Because the counts appear to be reproducible by different individuals, the method is believed to be an objective measure of the relative complexity of the photographs.

The Alabama Geological Survey and the University of Alabama, under contract to the EROS Program, are conducting a survey of potential users of ERTS data within the State of Alabama. The survey has two objectives: (1) to determine what organizations and industries are interested in using satellite information and how they wish to apply it; and (2) to provide the EROS Program with estimates of data requirements within the State as a guide for designing the production capacity of the Sioux Falls data center.

W. D. Carter has been investigating the origin of circular

[183] Daniel, J. F., 1970, Satellite (ERTS-A) network of ground data sensors—a user-oriented experiment: Natl. Symposium on Data and Instrumentation for Water Quality Management, Preprint 29, 14 p.

features revealed in Apollo photography of the southwestern United States. One in the Point of Pines area of the San Carlos Indian Reservation, eastern Arizona, is 4 mi in diameter and was recognized because it was enhanced by snow cover and low sun angle. Geologic mapping of the area is being done by C. S. Bromfield and J. C. Ratté; gravity and aeromagnetic surveys are being done by G. P. Eaton and D. L. Peterson; ground magnetic studies have been conducted by M. R. Brock and J. H. Hassemer; and induced-potential surveys are being conducted by Prof. J. S. Sumner and graduate students of the University of Arizona. The reasons for these studies are that the area lies 30 mi northwest of the Morenci copper deposit and is underlain by a magnetic high of similar magnitude and areal extent to those at Morenci and other known copper deposits in the area. The gravity survey has also revealed a high of large areal extent and closure associated with the circular feature; this high is currently interpreted to be an irregularity, perhaps an uplifted block of Precambrian granite and Paleozoic rocks, buried under the younger, stratified volcanic rocks (lavas and tuffs) at the surface. The surface rocks contain no metallic minerals, but the induced-potential surveys are being undertaken to determine whether the underlying rocks are mineralized at depth.

Two other circular features east of Clovis, N. Mex., in the Sand Hills area near Muleshoe, Bailey County, Tex., were identified by W. D. Carter as adjacent dark-gray patches in color infrared Apollo photography. Each is roughly 8 mi in diameter. Comparison with existing hydrologic maps of the area indicate that the dark patches are caused by high soil moisture content where the water table is at or very near the surface. The circles coincide with the greatest saturated thickness of the Ogallala Formation, the major ground-water aquifer in that area.

APPLICATIONS TO GEOLOGIC STUDIES

Mathematical modeling and thermal-infrared studies

A mathematical model previously developed by Kenneth Watson from the equation of heat conduction was checked against thermal-infrared flight data obtained over Mill Creek, Okla., in June 1970. Limestone and dolomite showed the expected predawn thermal contrast, but granite outcrops were markedly warmer than the model predicted. The model, when modified to take into account the passage of a warm front shortly before the flight, showed that such an atmospheric event would substantially raise the surface temperature of granite owing to the low thermal inertia of that rock. Modeling was extended to include the effects of lichen cover and rock porosity. The theoretical temperature variation curves thus derived indicate that a lichen cover 2 cm thick completely masks the thermal characteristics of a rock and that the thermal inertia of an average rock which has water-saturated pore space is independent of its porosity.

High-altitude infrared images of the Mill Creek area provided an opportunity to examine the effects of decreased atmospheric transmission and reduced spatial resolution which will be encountered in thermal imagery from satellites. An early-morning thermal image taken at 17 km, with a nominal ground resolution of 20 m, provides a practical demonstration that data of this type can be used to discriminate exposed geologic units of moderate extent.

Computer-recognition mapping of limestone and dolomite

Maps automatically generated from multispectral reflectance data for Mill Creek, Okla., involved computer recognition of materials on the basis of a training area selected for each unit to be discriminated. Studies by L. C. Rowan and R. D. Watson indicate that limestone was mapped with 82-percent accuracy and dolomite with 50-percent accuracy from data obtained some 900 m above terrain. Inaccuracies appear to be related to distribution of grass and rock rubble, which have reflectances not correctly categorized in the automated processing.

Studies by R. D. Watson of the spectral reflectance and photometric properties of selected rocks at this site demonstrate that rock type discrimination based on reflection differences is complicated by surface conditions such as weathering and lichen growth. Comparisons among freshly broken, weathered, and lichen-covered granite show that while both weathering and lichens change the reflectance amplitude, lichen coverage also considerably changes the photometric properties of the granite. Measurements of the spectral reflectance normal to the surface of both limestone and dolomite show limestone to be more reflective in the wavelength range from 380 to 1,550 nm. The reflectance difference decreases at view angles greater than 40° owing to differences in the photometric properties of dolomite and limestone. These results confirm that caution must be applied when attempting rock discrimination based on reflectance data.

Structural geologic applications of infrared data

Thermal infrared images of test sites in Oklahoma and Michigan were shown by T. W. Offield and L. C. Rowan to contain information on faults and fracture systems not obtainable from photographs. Faults appear as thermal anomalies where thermally contrasting rocks are juxtaposed or where water is concentrated in the fault zones; the width of water-rich zones along them is revealed more exactly than on photographs. Thermal images also show subtle stripes which cross rock outcrops and intervening areas of soil and probably record water distribution in rock fractures. Along the shore of Lake Michigan, predawn images show cool linear anomalies related to bedrock fracture systems beneath as much as 75 feet of glacial deposits. Color infrared photographs of the Beartooth Mountains, Mont., uniquely show the presence and distribution of mafic dikes and amphibolite bodies. Lineaments crossing grassy plateaus can be seen in other photographs but commonly can be identified as mafic dikes only by the marked contrast between the dark rocks and red vegetation in color infrared photographs. Some amphibolite bodies in granitic terrain can be detected and their contacts accurately drawn, owing to enhanced contrast between the two types of rocks in the near infrared.

Remote-sensing discrimination between rocks on basis of silica content

On June 25, 1970, a two-element infrared detector was flown over a sand quarry near Mill Creek, Okla., as part of a detailed investigation of the emission and reflection properties of common geologic materials. Data from this flight were used by R. K. Vincent and Fred Thomson (University of Michigan) in cooperation with Kenneth Watson (USGS) to produce an analog-processed image and a digital recognition map which discriminates exposed quartz sand and quartz sandstone from dolomitic limestone in the vicinity of the quarry. The implications of this technique are significant for both terrestrial and planetary remote-sensing missions and especially for studies of Mars.

Infrared studies of active volcanic regions

The May 1970 double flank eruption of Hekla volcano, Iceland, provided the opportunity for J. D. Friedman (r0601) (USGS) and Sigurđur Thórarinsson (University of Iceland) to observe in the field the relationship between preeruptive thermal emission from Hekla's main fissure eruption system and subsequent pyroclastic and effusive events associated with the May eruption. Earlier repose-period fumarole radiation was calculated to have been 6.7×10^{6} cal/sec using infrared signal-amplitude slices. The thermal-energy yield of the 1970 eruption is estimated at 7.3×10^{24} ergs, on the basis of total volumetric outflow of tephra and lava of known thermal parameters, as provided by Thórarinsson. By use of historical volumetric outflow data tabulated by Thórarinsson, the rate of nondissipated thermal energy buildup in the Hekla volcanic system was calculated to be 3.2×10^{23} ergs/yr with 8 percent variance since 1766, regardless of duration of repose intervals and magnitude or type of subsequent eruption, suggesting the possibility of steady-rate thermal-energy buildup at Hekla at a rate of 15 to 20 percent of the total heat flow from the entire neovolcanic zone of Iceland.

At the Kverkfjöll, Iceland, subglacial volcanic and geothermal area, aerial infrared thermographic and field reconnaissance data were used by Friedman, Thórarinsson, R. S. Williams, Jr. (USGS), and Guđmundur Pálmason (Iceland National Energy Authority) to estimate the advective heat transfer to a conspicuous melt-water stream to be 20×10^{6} cal/sec from a hidden subglacial geothermal source which may yield a total heat flow of 340 to 580×10^{6} cal/sec.[184] Infrared signal amplitude slices delineate more than 120 points of thermal emission at Kverkfjöll. An ice cauldron 630 by 590 by 60 m is estimated to have yielded 1.2×10^{23} ergs during its formation. The hidden geothermal source may be a subglacial caldera or subglacial thermal springs alined along a continuation of the structural element marked by the recorded points of thermal emission.

In a cooperative field and aerial photographic investigation by J. D. Friedman and R. S. Williams, Jr. (USGS), Sigurđur Thórarinsson (University of Iceland), Harald Svensson (Lunds Universitet), and Karl-Erik Johansson (Småland Nature Conservancy), patterned ground in Iceland's interior-upland surfaces, consisting largely of frost-crack polygons 14 to 24 m in diameter, was found to be particularly well delineated on infrared Ektachrome aerial photographs because of increased vegetation vigor in the cracks in contrast to the polygon centers. Field investigation revealed that the fossil ice-wedge cracks disrupt identifiable and dated tephra horizons several inches to several feet below the present soil surface. The tephra horizons resulted from historical and prehistorical eruptions of Hekla. Most of the polygons dated thereby seemed to have formed during the "Little Ice Age", between 1550 and 1730 A.D., on upland surfaces lacking in true permafrost conditions.

Thermal-infrared images (8–14 μm) obtained by J. D. Friedman (USGS) and Dale Matlack (U.S. Forest Service) show a horseshoe pattern of anomalies around the rim of the main crater at Mount Baker, Wash., no anomalies in the Bailey Peak area, Oregon, and more than 20 springs in Crater Lake, Oreg., along the coast of Wizard Island, where temperature variations between spring effluents and lake surface water are indicated.

Infrared surveys of arctic soil and vegetation

A study by G. W. Greene of thermal infrared imagery provides insight into drainage conditions in permafrost during summer because relatively dry, well-drained areas are as much as 10°C warmer than poorly drained areas. High-center polygons can be distinguished very readily from low-center polygons by contrasting temperature patterns on thermal infrared imagery. Sand and gravel deposits and rock outcrops can be detected by their higher surface temperatures during summer daylight hours.

In arctic and subarctic soil, temperature around plant roots is the factor which, more than any other, appears to determine the relative vigor of vegetation as detected by color infrared photographs. In the absence of variations in plant stress resulting from deficiencies or excesses in nutrition, damage, or insect infestation, the plant vigor of a given species serves as a rough measure of active-layer conditions in the root zone. Thus, areas covered by vigorous vegetation are likely to be underlain by a relatively thick, well-drained active layer. Conversely, sparse vegetation lacking in vigor could indicate a thin, poorly drained active layer.

[184] Friedman, J. D., Williams, R. S., Jr., Thórarinsson, Sigurđur, and Pálmason, Guđmundur, 1971, Infrared emission from Kverkfjöll subglacial volcanic and geothermal area: Jökull, Reykjavík. [In press]

Computerized pattern recognition of terrain classes in Yellowstone National Park

Pattern recognition of terrain classes was achieved by H. W. Smedes (USGS), in collaboration with H. J. Linnerud and S. G. Hawks (EG&G, Inc.), using the three emulsion layers of color film or of color infrared film as a three-band spectrometer of low spectral but high spatial resolution.

Image density data from each of the three color emulsions were entered into a digital computer program that produces terrain maps by use of clustering techniques.

Color transparencies were scanned by a Mann Trichromatic Microdensitometer at a resolution corresponding to a spot about 10 m in diameter on the ground. All three film dye layers were sampled simultaneously by means of beam-splitters and filters. Triads of density values were obtained from each area element on the transparency and were recorded on magnetic tape. The data were digitized to nine-bit accuracy. Characteristic spectral signatures inherent in the data—presumably representing terrain classes—were identified by the application of clustering techniques in three-color space. Each datum point was assigned to a class on the basis of its spectral signature, and each class was then assigned a letter character. Computer-generated overlays were made to fit photographic enlargements of the transparency at a scale of approximately 1 inch = 110 m. Existing ground-control data enabled these classes to be labeled as to true terrain class.

The following terrain and vegetation classes were automatically mapped from color and color infrared film, with overall accuracy equal to or better than that of previous multispectral scanner classification (better than 85 percent), and with far greater spatial resolution: (1) deciduous trees, bushes, and bogs; (2) evergreen trees; (3) bedrock, largely granitic gneiss, and rhyolite tuff (in quarry); (4) bedrock, largely basalt and amphibolite; (5) talus; (6) rock and talus in shadow; and (7) shadows of trees and cliffs.

The spectral bandwidths used in this study are similar to those of the Earth Resources Technology Satellite (ERTS) sensor, and the resolution is about eight times better. The accuracy of classification (better than 85 percent) indicates how well the ERTS sensors might be expected to perform in classifying similar terrain and agrees closely with the results of ERTS simulations made using scanner data.

In continuing studies of computer mapping of Yellowstone National Park test areas, Smedes and M. M. Spencer and F. J. Thompson (University of Michigan) found a method to minimize classification errors caused by the effect of shadows, topography, and scan angle on spectral radiance of terrain features of a single class. Preprocessing of data obtained by 12-channel scanning spectrometer showed that misidentification was significantly reduced by using a normalized scan-angle function transformation or by relating each channel to the sum of all channels. These techniques also greatly reduced the preparation, processing time, and human intervention because fewer training areas were required.

High-altitude photographs for geomorphic studies and land-use planning, southern Arizona

Maps of soil associations and geomorphic features of an 8,000-sq-mi area in southern Arizona, between Tucson and Ajo, are being compiled by R. B. Morrison for publication at 1:250,000 scale. Primary input for these maps is based upon interpretation of color aerial photographs, obtained from about 60,000 feet above ground terrain by high-altitude National Aeronautics and Space Administration (NASA) aircraft, supplemented by ground-control traverses in selected areas. The maps are designed to provide data on the distribution of several types of geologic terrain parameters relating to surficial deposits and landform characteristics, such as local relief and slope. This study is proving remarkably successful in producing quickly a series of comprehensive integrated maps that display many data fundamental to proper land-use planning and development in a large area where such data have not previously been available.

Remote sensing of coastal features

In a continuing aerial photographic and infrared thermographic study of the Holocene coastline of New England, J. D. Friedman, R. N. Oldale, and R. S. Williams, Jr. (p. B101–B107), prepared a 1:24,000 scale black-and-white photomosaic of Nantucket and nearby islands off the Massachusetts coast from Ektachrome infrared Aerographic film coverage of May 1969 for a study of the history of coastal changes of Nantucket and contemporary shoreline processes. The photomosaic and derived shoreline planimetry show detailed changes and trends as well as littoral-zone sedimentation features.

Fracture pattern in the southwestern United States mapped on Apollo photographs

A fracture and lineament map covering a 100-mi swath from Baja California to west Texas was made by S. J. Gawarecki using Apollo 6 stereophotography. Interpretation of the structural features on the photographs was enhanced by the low solar angles (20°–30°) prevailing during the morning of the photographic exposure. Solar angles near 30° were found to provide optimum illumination in the area of study for both color contrast and structural rendition, through shadow enhancement of topography. The most conspicuous fracture alinements are those trending north-northwest, east-northeast, north-northeast, and west-northwest. West of the Arizona–New Mexico State line the north-northwest trend is dominant, whereas to the east of the State line the north-northeast trend is strong. Four Quaternary basaltic lava fields, from the Pinacates (Mountains) in Sonora, Mexico, to the West Portrillo Mountains in New Mexico, have north-northeast-trending volcanic cone or fissure alinement directions. This trend is strongest in the West Portrillo lava field, which is alined structurally with the Rio Grande graben system to the north.

A west-northwest eruption line cutting the West Portrillo field may be an extension of the lineament found in Texas, but this feature cannot be traced westward. A comparison of the fracture patterns annotated on the space photography with a published map of the copper belt in Arizona and New Mexico reveals striking parallelism between the major fracture trends and the adjoining boundaries of the belt. Further comparison with contour maps of the depths to the Moho and Conrad discontinuities strongly suggests a relationship between the crustal structure, the copper belt, and the fracture pattern. The fracture trends and the copper belt parallel the Moho depth contours. The Conrad depth contours define a shallow structure which coincides with the copper belt and major fracture trends. The initial implication is that crustal thickness, in this area at least, controls the regional fracture pattern.

Satellite magnetometry provides accurate map

Magnetometer data obtained from the U.S.S.R. Cosmos 49 satellite strongly suggest to Isidore Zietz that the satellite measurements are an accurate representation of the earth's magnetic field based on measurements made from aircraft over the continental United States and shipborne measurements in the North Atlantic. Previous analysis of these data showed, after removal of the main dipole field, a consistency with belts of broad anomalies known from surface and near-surface magnetic measurements.

Radar display of fine-grained alluvium near Flagstaff, Ariz.

Side-looking radar images, of 25-cm wavelength, obtained over the Flagstaff, Ariz., area were evaluated by G. G. Schaber and found to have significant geologic value. Regions of sand- and silt-sized alluvial materials were conspicuous on the radar images owing to their extremely low reflectivity at the 25-cm wavelength. These fine-grained alluvial deposits are not discernible on high-quality aerial photographs taken of the test area or on 0.86-cm side-looking radar images of the same area obtained with the same "look direction" and flightline azimuth.

Kelsh mapping on aerial color photographs

Aerial color positive transparencies at 1:20,000 scale were used by M. W. Green at × 5 enlargement in a Kelsh photogrammetric plotter to aid geologic mapping of part of the Continental Divide 7½-minute quadrangle, McKinley County, N. Mex. Geologic relationships within the mapped area previously had been established by fieldwork.

An area of about 5 sq mi was mapped at 1:24,000 scale in about 33 hr. The map showed more detail than a map of the same area produced in the field by the planetable method. In the vicinity of planetable control points, the contacts obtained by the Kelsh method are believed to be at least as accurate as those obtained by the planetable method and are more accurate between control points.

The mapped area is underlain by gently dipping, brightly colored, well-exposed sedimentary rocks which crop out along cliffs having about 1,100 feet of relief, as well as in reentrants in the cliffs and in badlands below. Access to planetable stations is only moderately good. It is estimated that for areas similar to this, including much of the Colorado Plateau, the field-controlled aerial color-Kelsh method of geologic mapping is as much as 50 percent more rapid, accurate, and sensitive than the planetable method.

APPLICATIONS TO HYDROLOGIC STUDIES

Mesoscale temperature variations on a glacier valley wall

W. J. Campbell reported that during the last 5 yr detailed surface temperature fields have been measured on the north valley wall, the lake, and the glacier terminus of South Cascade basin, Washington. These measurements were made from two peaks within the basin using Barnes PRT-5 radiometers with beam cones of 2° and 0.15° under a great variety of meteorological environments during spring, summer, and autumn. The temperature lapse rate of the ambient air within the basin was measured by four long-term recording thermographs installed on two adjacent peaks, on a ridge at midglacier elevation, and at the outflow of the terminus lake. During radiometric observations the wind vector was measured at the lake outflow and at the radiometric site. During clear sky and light wind conditions the surface temperature of the valley wall assumes a highly heterogeneous character, with temperatures as high as 40°C on two talus cones and with gradients of surface temperatures on the valley wall as great as 15°C per 100 m. During these clear conditions diurnal temperature changes of more than 40°C occurred on parts of the valley wall, while the ambient air temperatures varied only on the order of 10°C. During windy and cloudy conditions the range of the temperature change was less than under clear conditions, but change was frequently more rapid. Also, the character of the surface temperature field was less heterogeneous than under clear skies. Certain mesoscale meteorological features, such as drainage winds, had profound effect on the temperature structure of the glacier valley wall and the lake surface. It is possible to predict the valley-wall temperature structure for several classes of mesoscale air circulation, and it is concluded that before one can properly interpret satellite and aircraft infrared images of glacier valleys one must have some data on the mesoscale atmospheric flow of the individual basin.

Alafia and Peace River basins, Florida

A. E. Coker reported on an experiment conducted in the Alafia and Peace River basins using remote-sensing techniques to detect areas subjected to fluoride and phosphate contamination. Observations were made of the integrated effects of these contaminants on vegetation, terrain reflection, and temperature.

The University of Michigan's scanner system was used to detect multispectral radiation consisting of various combinations of 18 spectral bands from 0.32 to 14.0 μm over selected test sites. The multispectral data were processed on the University of Michigan special-purpose analog computer in order to detect vegetation chlorosis and necrosis and to enhance terrain reflection and surface temperatures.

Terrain temperature patterns (obtained from processed 8–14-mm data) and ultraviolet terrain patterns (obtained from processed 0.50–1.8-mm data) and combinations of the two showed distinctive patterns which can be correlated with areas known to be subjected to fluoride and phosphate contamination in the Alafia River basin, Florida.

Biscayne Bay, Fla.

M. C. Kolipinski and A. L. Higer are developing a method that employs multiband imagery and a digital simulation model for forecasting what ecological changes in the benthic communities could occur in south Biscayne Bay and Card Sound as a result of discharging heated water into the bay.

Underwater features were identified and automatically mapped with the processing of multispectral-scanner data obtained from an overflight at an altitude of 6,500 feet. The area covered included the bay region currently affected by thermal discharge from a powerplant.

Recognition maps of underwater community types were created by electronically processed combinations of video signals in selected narrow spectral bands. A system of computers was programed to identify each site type at different water depths to compensate for variations in reflectivity. The maps were printed in different colors and superimposed to provide a color composite map of recognized features in the study area.

Automatic mapping of the benthic plants by multiband imagery and the mapping of isotherms and hydrodynamic parameters by the digital model, when used together, can become an effective predictive ecological tool. Benthic plant communities succumb to temperatures exceeding 90°F for an extended period of time. With the two systems it is possible to predict conditions that could adversely affect the benthic communities. With the advent of the Earth Resources Technology Satellites (ERTS) and space platforms, imagery data of Biscayne Bay could be used in conjunction with water-level and meteorological data for continuous ecological monitoring of the bay.

Application of remote-sensing techniques to estuarine studies

Conventional color and color infrared aerial photographs, multispectral black-and-white aerial photographs, and infrared imagery of the Sabine-Neches Rivers estuary, Texas-Louisiana, were obtained during three missions described by K. W. Ratzlaff. The missions were flown during different tidal and streamflow conditions.

Analysis of the data indicated that tidal currents, current patterns, and the inflow of warm turbid wastes and petroleum wastes can be detected. The detectability of these phenomena primarily depends on the type of sensor used, film-filter combination used, or the relative turbidity of the wastes and the receiving water. Except when turbidity of the receiving water is high, the detectability of most of the phenomena on color and color infrared photographs generally is excellent. The dispersion of warm turbid wastes is readily detected by infrared imagery and multispectral black-and-white photographs. The detectability of petroleum wastes on multispectral black-and-white photographs obtained through a Wratten 47B filter is good but decreases as filter transmittance wavelength increases. Current patterns and tidal intrusion were readily detected on the color and color infrared photographs.

Central New York lakes

In continuing study of New York lakes, J. M. Whipple noted that there are diverse water management uses for the information presented by thermal infrared imagery. Data applications include industrial waste-water discharge inventory, lake basin water-budget analysis, design of treatment facilities, and generating-plant siting as related to thermal discharge criteria of the water-quality standards. For example, in Onondaga Lake, near Syracuse, the surface expression of a submerged sewage outfall had been observed on repeated images, as well as industrial discharges not primarily thermal in nature. It was also noted that the discharges from a sewage treatment plant, municipal combined sewers, and industrial cooling processes are all located in close proximity in one part of the lake. A feature such as this may influence treatment-facility design because of the thermal dependence of dissolved oxygen and biochemical oxygen demand.

Imagery of the Oswego Harbor on Lake Ontario has shown relationships of ice and water, wind-driven lake circulation, Oswego River flow, and the thermal discharge from a generating plant. This information is relevant to design of generating-capacity increase and disposal of additional waste heat, as well as to harbor design analysis.

Additional study of thermal loading at Roxboro Lake, N.C.

Thermal infrared imagery was used by J. F. Turner, Jr., W. L. Yonts, Jr., and K. L. Lindskov for Roxboro Lake, N.C., to help map the distribution of water-surface temperatures and a 1-hr change in distribution during a winter period when surface temperatures ranged from 6° to 22°C. Image quality and resolution were poor for the entire thermal range. In the area where resolution permitted, the imagery was valuable in locating thermal interfaces and in detecting their movement (primarily because of wind).

The color infrared photography was evaluated for use in detecting algae. Although there has been a noticeable buildup in algae in heated areas of Roxboro Lake, the range in concentrations (0–0.14 mg/l for chlorophyll index of total biomass) was not high enough to register on the color film. The color film did, however, identify the extent and configuration of a cloud of sediment in the upstream areas of the lake. Comparison of the color photographs suggests that film type S0397 (with Standard haze filter) and film type S0117 (with Wratten 15G filter) are equally effective for detecting turbidity.

Microwave emission from snow

M. F. Meier reported the completion of a 2-yr study of the microwave emission characteristics of snow. This effort, performed by the Aerojet-General Corp. in conjunction with the U.S. Geological Survey, included development of theory and numerical models, laboratory measurements, analysis of overflight data, and controlled field experiments to establish the physics of microwave emission by snow. Dielectric constants of six natural snow samples were determined at wavelengths of 0.8 and 2.2 cm by use of an ellipsometer. Field measurement of brightness temperature as a function of snow conditions was made at wavelengths of 0.8, 2.2, 6, and 21 cm. A carefully controlled experiment indicated that the brightness temperature exhibits a slowly varying but pronounced decrease in response to increasing snowmass (water equivalent) for dry snow. The 0.8-cm brightness temperatures decrease approximately 50°K as the depth of the snowpack increases from 0 to 40 cm of water equivalent. A theory for the microwave emission from layered media which neglects scattering has been developed and adapted to numerical calculation of brightness temperatures of snow over soil.

APPLICATIONS TO CARTOGRAPHIC STUDIES

The U.S. Geological Survey in close coordination with the Earth Resources Observation Systems (EROS) Program and in cooperation with the National Aeronautics and Space Administration (NASA) has continued investigations of cartographic applications of data from remote sensors carried in spacecraft and aircraft. In previous years the emphasis was on developing basic technology to produce cartographic products from available space imagery for use by the general public and earth resources investigators. This past year, however, an additional emphasis was given to proposed cartographic applications of the first Earth Resources Technology Satellite (ERTS-A) and Skylab data. A group of experiments proposing to study the utility of ERTS-A data and Skylab data have been submitted to NASA for funding support, and studies have been pursued using in-house expertise as well as academic and commercial experts to develop a capability of producing useful products from remote-sensor data.

Photomaps from space imagery

After the successful experiments of the past year in producing a 1:250,000-scale photomap of the Phoenix, Ariz., quadrangle and distributing it for comments, a new edition of the same quadrangle was compiled from two Apollo 9 photographs and printed in combination with selected features from the standard line map. On the other side, the complete standard line map was printed head to head so that by cutting the map in half two renditions of the same area can be compared side by side. Ten thousand copies of this photomap were printed, and the map was placed on public sale. The United Nations has selected this product for worldwide distribution as an enclosure to its periodical World Cartography. Comments on this map, which are overwhelmingly favorable, are being evaluated to provide guidance for designing future products.

A photomap at 1:500,000 scale covering an area of approximately 50,000 sq mi south of Phoenix, Ariz., and extending from long 109°00′ to 116°00′ W. and from about lat 31°15′ to 33°30′ N. was printed as an experimental edition. The sheet covers the same area as the southern half of the Phoenix Sectional Aeronautical Chart published by the National Ocean Survey. The photographs were taken on NASA's Gemini and Apollo missions, principally with handheld Hasselblad cameras of 80-mm focal length and 70-mm format. They were rectified and fitted to the planimetric base of the existing chart. The new photomap combines space imagery with selected cartographic line data and contours taken from the conventional aeronautical chart. Because the space photographs were taken from about 125 nautical mi above the earth, the resulting rectified photographs are very nearly orthographic and fit the existing planimetry rather well. Most of the existing marginal data and grid data from the original chart were kept intact. This product has been distributed to interested cartographers and map users, and comments on the advantages and disadvantages of photomapping from space photographs have been solicited.

A photomap at 1:250,000 scale is being prepared of the Atlanta, Ga., area. Four photographs taken on the Apollo 9 mission with a Hasselblad camera of 80-mm focal length cover the area, and they are being rectified in a Wild E4 rectifier. After rectification, they will be scaled to the revised planimetric drawing of the existing 1:250,000-scale line map. Upon completion of the mosaic and the preparation of a set of random-dot negatives, colors best suited for the area will be selected and a decision made regarding sample printing and distribution.

Cartographic enhancement of photomaps from space imagery

Several cartographic experiments were conducted in an effort to increase the information content and enhance the imagery of photomaps prepared from space photographs. A masking technique is being used to print areas of little or no relief in light buff and steeper areas in a darker shade of brown. This technique tends to emphasize relief features. Other masks will be prepared so that the imagery of woodlands will be shown in dark green, cultivated fields in lighter green, and urban areas in orange. An effort is being made to further enhance the natural shading by applying red dye to both positive and negative continuous-tone films of the photoimagery. The dye, if applied to the negative, lightens harsh shadows and, if applied to the positive, darkens areas overhighlighted by the sun angle. A contour drawing is used as a guide for applying the dye.

Thematic mapping and special image processing

The Geological Survey started investigating methods of depicting thematic data by inviting proposals from commercial firms to study methods and equipment for an analog system capable of extracting images of snow, water, infrared (IR) reflective vegetation, and massed works of man from multispectral photographs. The Philco-Ford Corp. proposed the most feasible approach, and an optical density-slicing method to isolate the thematic imagery and print it on color foils was demonstrated with the use of a variety of satellite photographs and high-altitude aerial photographs. Further studies by the Geological Survey showed that specialized image processing in a conventional photolab could be used to emphasize water and water-related phenomena. Tests have demonstrated that infrared photographs processed with sharp masking techniques can show the water channels and the vegetation on the surface of the water.

As a requirement for the EROS Program, a prototype thematic mapping system with both analog and digital processes will be developed at the research center in McLean, Va., and later installed at the Sioux Falls data center. The basic design and system concepts were outlined by a special task force of the Geological Survey, and a contract for a data-manipulation subsystem has been arranged with a commercial firm. The system is planned to be in operation by the launching of ERTS-A in 1972.

Register of multispectral images

Several types of remote sensors record distorted images, and these images must be corrected geometrically before they can be used for cartographic products. To provide data for transformation, these images must be correlated with geometrically correct images of the same area, such as an aerial photograph taken with a metric camera. A research project during this fiscal year studied the feasibility of using the image correlator built by the BAI Corp. for the Geological Survey to correlate multispectral images. During the first phase of the project, an attempt was made to correlate black-and-white transparencies from the B, C, and D cameras of Apollo 9 experiment S065. These cameras recorded the same ground area in three different spectral bands. Plate coordinates were obtained for several corresponding points, and the BAI correlator was used to ensure that the same points were identified on each scene. These plate coordinates were then manipulated by linear-transformation and space-resection computer programs to determine how accurately the images could be brought into register with one another by the use of scale change and rectification. The difficulty in correlating one image with another due to the different spectral bands of the images was also studied.

In the second phase of the project, three return beam vidicon (RBV) images of the same scene were used. These images had been obtained by scanning a color aerial photograph with an RBV camera. Filters were introduced to produce separate images from the blue, green, and red colors of the original photograph. The purpose of this phase of the project was to determine what effect the RBV camera system has on image geometry. The correlation procedure was the same as that used with the S065 images. Results indicated that 9- by 9-inch enlargements of the S065 images could be registered to a standard error of 270 to 280 μm with only scale change and to a standard error of 90 to 115 μm with scale change and rectification. The maximum errors were as much as twice the standard error. A better calibration of the S065 cameras, particularly the principal-point location, would probably have improved the results. The 9- by 9-inch RBV images were registered with only a scale change to a standard error of about 100 μm. This is approximately the size of one resolution element of the RBV system. The main conclusion of this project was that the BAI correlator was not successful in locating all points on the multispectral images. Tone reversals, particularly those from the red band to the infrared band, seriously reduce the success of correlation, especially in agricultural areas. Natural terrain seems to correlate better. Thus, it is necessary to judiciously select points to be used, and this requirement could seriously reduce the usefulness of the BAI correlator for registering multisensor images. Since only a small sample of points was used, no valid conclusion on the overall accuracy of registering could be reached. Additional studies on correlating multispectral aerial photographs and images from infrared line scanners are planned.

Infrared sensing of targets in wooded areas

Two sensing systems which respond to thermal infrared radiation were evaluated for their potential usefulness in locating control points in wooded areas. The systems investigated were the AGA Corp. Thermovision System 680 and the Barnes Engineering Co. infrared camera, Model T-102. These instruments are sensitive to infrared radiation in the 2.0- to 5.6-μm and 8- to 15-μm wavelength regions, respectively. Various targets, such as dry ice, aluminum foil, a bucket of charcoal, and a propane torch, were placed in a vegetated area, and images of the targets were acquired with each instrument from the roof of a building nearby. Black-and-white 35-mm photographs of each target and its background were also taken to determine if the target locations could be transferred from the infrared images to the photographs. The results of this investigation indicated that all the warm targets and the cold dry-ice image quite well. The aluminum foil appeared on some exposures but not on others. Because of the low resolution of these infrared systems, the background was imaged rather poorly, and therefore the target locations could not be accurately transferred to the photographs. However, with improved resolution in infrared imaging systems, thermal targeting of control points should prove useful in photogrammetric mapping. The U.S. Bureau of Land Management is planning further trials by use of an airborne infrared scanning system in Oregon. This work is being monitored and supported by the EROS Program of the Geological Survey.

Calibration of the RBV system for ERTS

The return beam vidicon (RBV) television system to be launched in March 1972 aboard ERTS-A will provide a large number of frame-format images of the earth. A geometric calibration of the system is essential for subsequent data processing, distortion correction, and photomap preparation. U.S. Geological Survey engineers have modified a Mann comparator and are cooperating with NASA in obtaining calibration data for the RBV system. The reseau pattern of 81 points in a 1-inch format has been measured on the face of 23 RBV tubes. Four independent measurements were made on each reseau point. The average standard error of all measurements is less than 1.5 μm, and the final accuracy of the mean position of the reseau in a defined coordinate system is less than 2.0 μm with a 90-percent confidence level. The calibration data on the RBV reseau are approximately one order of magnitude more accurate and statistically more reliable than any previous television calibration data. Further efforts at RBV calibration are being directed toward lens calibration. A Kern DKM 3 theodolite was modified for use in making calibration measurements and installed on a milling-machine test stand at RCA Astro Electronics Division, Princeton, N.J. The reseau will be sighted through the 127-mm lens, and a photogrammetric lens calibration will be performed. Pointing accuracy of better than 2 seconds of arc is required.

RCA has produced some laboratory-model RBV images by scanning aerial photographs, and a research project is underway to investigate electronic distortions by analyzing these images. Some of the work is under contract with the University of Illinois. Preliminary analysis shows root-mean-square distortion of about 72 μm at reseau scale (1-inch format) and a maximum distortion at the format edge of about 175 μm. These rather large distortions are extremely stable, with a random component of about 2 μm obtained for 20 images over a period of several days. Thus it appears feasible to develop procedures for removing the systematic distortions so that the images could be used for photogrammetric purposes.

Plotting grids on space photographs

A computer program has been prepared by Ohio State University under a U.S. Geological Survey contract by which the coordinates of a reference grid may be generated for plotting on space photographs. A Universal Transverse Mercator (UTM) grid is computed by the program from photocoordinates of image points and plotted on the photograph by an automatic plotter. A latitude and longitude reference graticule may also be generated by this program. Since the photographs are unrectified, the scale may vary within the format of any photograph, and the grid will not be a series of uniform squares. However, coordinate values can be read on such a photograph by interpolation between grid lines. This procedure is useful for wide-angle photographs which cannot be precisely rectified because of relief and earth curvature.

Computer program for image-point displacement studies

A computer program has been written by DBA Systems, Inc., under a U.S. Geological Survey contract to analyze the effects of terrain relief, atmospheric refraction, earth curvature, and camera orientation on space photographs. Image displacements can be determined on both aerial and space photographs that have undergone various amounts of rectification and have been fitted to either a transverse Mercator, a Lambert conformal, an azimuthal equidistant, or a polar stereographic projection. Thus, the errors can be predicted for aerial and space photographs being considered for use in orthophotomapping. A byproduct of the program is rectification parameters for input to the Wild E4 rectifier.

Land-use data file

A study has been initiated at the request of EROS geographers to determine the feasibility of using aerial and space photographs for establishing and maintaining land-use data files. The area covered by the Phoenix 1:250,000-scale quadrangle has been designated as the test area for the research project, and plans include setting up two files—one for highway data and one for land-use data. The land-use file will be based on a 1-km grid superimposed on the area, with a data record stored for each grid intersection. The data are digitized on punched cards with the coordinatograph of an AP/1 stereoplotter.

Data bank of control for ERTS imagery

A data-bank system has been developed to store and retrieve photoidentifiable ground points for control of ERTS imagery. The system is designed for 1:1,000,000-scale ERTS images, which will require control points spaced at about 40-km intervals over the entire United States. The user may input the approximate coordinates of the center of the area of interest, and the computer prints out a list of the control data within a

10,000-sq-mi area around this center. For each point the following information is given: (1) latitude and longitude, (2) UTM (Universal Transverse Mercator) coordinates, (3) elevation in feet and meters, (4) description, and (5) reference codes that identify maps in the IMW (International Map of the World), 1:250,000, 15-minute, and 7½-minute series on which the point is located.

Nationwide coverage of these control data is expected to be compiled and stored before the launching of ERTS-A in 1972.

Datacolor system

To broaden the capacity and capability to analyze photographs for earth-resources studies, a model 703 Datacolor density slicer was acquired. This instrument separates the gray scale of a backlighted transparent image into as many as 32 increments and displays the increments in distinctive colors. Features which show particular photometric responses may be isolated, displayed, and quantified by this system.

EROS user research facility

The following user research facilities for the EROS Program have been made available at either the Branch of Special Maps, Silver Spring, Md., the Topographic Division Research Center, McLean, Va., the General Services Administration Building, 18th and F Sts., N.W., Washington, D.C., or the Special Projects Office, Reston, Va.:

- File of aircraft and space film
- Precision enlargers, rectifiers, and viewers
- Three-band additive viewer
- Black-and-white photoprocessing laboratory
- Cartographic facilities
- Image density slicer (electronic)
- Image correlating and measuring system
- Microdensitometer
- Automatic plotter
- Graphic digitizer
- Color photoprocessing laboratory.

GEOLOGIC AND HYDROLOGIC INVESTIGATIONS IN OTHER COUNTRIES

As a result of its growing interest in scientific and resources problems that extend beyond the limits of the United States and its growing involvement with international agencies or programs on behalf of the U.S. Department of State, the U.S. Geological Survey has steadily increased its participation in scientific research, technical assistance, and representational activities abroad.

During 1970 the Geological Survey increased the scope of its cooperation with other countries in the research on, and application of, new techniques for appraisal of geothermal resources, in geochemical exploration, in the applications of remote sensor and geophysical techniques for mapping, and in testing other methods applicable to the appraisal of resources. Geothermal studies were undertaken in five countries, and resulted in the identification of an economically significant geothermal energy resource in Indonesia. Survey geologists helped organize and provide technical leadership for a geochemical seminar on problems in the humid environment sponsored by United Nations agencies, involving scientists from 10 countries in Asia and the Far East. New aeromagnetic, radiometric, orthophotographic, and multispectral photogeologic techniques were applied to geologic or hydrologic mapping and resources appraisal in six countries.

Most of the Geological Survey's international work involves assistance to developing countries at the request of the Department of State, sponsored by the U.S. Agency for International Development, by international organizations, or directly by the host governments. In the past year, several of these technical assistance projects have yielded results of major importance. For example, in Colombia, the Geological Survey's cooperative minerals inventory program with the Instituto Nacional de Investigaciones Geológico-Mineras, resulted in a vast amount of geologic and structural data that have recently been synthesized and interpreted in a study of the structural development of the northern Andes and their relation to continental accretion.

In Saudi Arabia the Geological Survey's program over about a quarter of a century on behalf of the Ministry of Petroleum and Mineral Resources has amassed geologic, hydrologic, mineral-resource, and related knowledge. Much of this information is now being synthesized in the preparation of a tectonic map of the Arabian Peninsula.

In the sixth year of a 7-year program in cooperation with the Liberian Geological Survey, a diversified program of geoscience investigations is leading to compilation of the first geologic map and shaded-relief geographic maps of the entire country. Interpretation of airborne geophysical data has yielded a tectonic map of the country and discovery of a 25-mile-wide potential petroleum province along the continental shelf. Geochronology and paleomagnetic work in cooperation with the Massachusetts Institute of Technology has yielded highly significant interpretations of the metamorphic terrane, dike swarms, and the Precambrian complex, as well as new information concerning time and mechanism of opening of the Atlantic.

In Indonesia the new concepts of plate tectonics are being used to decipher the geologic history of the Indonesian archipelago and to understand the dynamic geologic processes now active there.

In the field of hydrology the Geological Survey has been an active participant in and supporter of the International Hydrological Decade (IHD) which began in 1965 under the aegis of the United Nations Educational, Social, and Cultural Organization (UNESCO). During 1970, Survey hydrologists participated in some 10 IHD conferences, seminars, and working groups on such diverse topics as the hydrology of droughts, the world water balance, the application of mathematical and statistical methods in hydrology, and the practical and scientific results of the IHD and international cooperation in hydrology at mid-decade (1970). More detailed information on the Geological Survey participation in IHD investigations is given on p. A93 and A131.

In the field of igneous petrology, work in foreign countries has led to a better understanding of ore-forming processes and to practical guidelines in the search for ore. Projects involving the study of ultramafic rocks and associated chromite deposits in the Philippines (1957–63) and Pakistan (1968–71) have shown that chromite in alpine-type complexes is not random in its disposition but is generally restricted to specific geologic units and has a predictable relationship to internal structural features within the igneous mass. This knowledge may help in the search for chromite in other ultramafic complexes.

Through such cooperative work abroad, the Geological Survey is helping introduce new geoscience techniques and applications in other countries and, concurrently, studying geologic environments for a better understanding of geologic problems and processes.

Since the beginning of the Geological Survey's technical assistance program in 1940, more than 1,491 technical and administrative documents authored by Survey personnel have been issued. During calendar year 1970, 79 administrative and (or) technical documents were prepared, and 99 reports were published or open filed (see table 2).

Technical assistance remains the largest foreign commitment of Geological Survey personnel (table 3). During the last 31 years the Geological Survey has provided earth-science specialists for about 1,200 assignments in more than 80 countries. During fiscal year 1971 the Geological Survey conducted long-range technical assistance programs in 14 countries in South America, Africa, Asia, and the Far East, and undertook short-range programs in 30 countries. This assistance is provided under the authority of the Foreign Assistance Act of 1961, as amended, in cooperation with the U.S. Department of State. Most of the programs are sponsored by the Agency for International Development. In addition, the Geological Survey had 22 employees on detail to international organizations under authority of the Federal Employees International Organization Service Act (P.L. 85-795, as amended).

The U.S. Geological Survey continues to aid in training participants from other countries in various phases of mapping operations and in organizing academic programs at selected universities in the United States. During the fiscal year, 149 participants came from 39 countries. They were sponsored by the United Nations, U.S. Agency for International Development, foreign governments, other international organizations, and special fellowship funds.

Table 2.—*Technical and administrative documents issued in calendar year 1970 as a result of the U.S. Geological Survey technical assistance program*

Country or region	Reports or maps prepared: Project and administrative reports	Reports or maps prepared: Reports approved for publication by the U.S. Geological Survey and counterpart agencies	Reports or maps prepared: Reports published in technical journals	Reports or maps prepared: Reports published or released by the U.S. Geological Survey
Algeria	—	1	—	—
Argentina	2	—	—	—
Austria	—	—	2	—
Brazil	13	11	8	3
Colombia	7	10	2	6
Costa Rica	1	—	—	—
Chile	1	1	—	2
Ethiopia	1	—	—	—
Guyana	—	—	1	—
India	1	—	—	—
Indonesia	6	3	—	2
Iran	1	1	—	—
Italy	1	1	—	—
Korea	2	—	—	—
Liberia	4	8	—	6
Libya	—	—	—	2
Mexico	—	—	1	—
Nigeria	—	1	—	—
Pakistan	5	2	1	—
Peru	1	1	—	1
Spain	1	—	—	—
Saudi Arabia	10	30	15	44
Taiwan	1	—	—	—
Thailand	1	—	1	—
Turkey	12	—	—	—
Vietnam	1	—	—	—
General	7	2	1	1
Total	79	72	32	67

Table 3.—*Technical assistance to other countries provided by the U.S. Geological Survey during fiscal year 1971*

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	4	Geologist	D	1	Hydrogeology.
	1	Hydrologist	D		
Brazil	13	Geologist	A	1	Radioisotopes in hydrology.
	2	Geophysicist	A	1	Chemistry.
	2	Hydrologist	A	3	Hydrology.
	1	Mining engineer	A	1	Uranium geology.
	1	Senior computer programmer	A	2	Economic geology.
	1	Computer data processing specialist	A	6	Electric systems regulation and operation.
	1	Senior mineral development specialist	A	1	Exploration geology and geochemistry.
	1	Metallurgist	A	1	Special cartography; illustration preparation and reproduction.
	1	Senior rate engineer	A	2	Analytical techniques.
				1	Map making; photogrammetry.
				1	Remote sensing.
				1	Geology; geologic administration.
				2	Exploration for radioactive material.
				2	Laboratory management.
Chile	2	Hydrologist	C	1	Engineering geology.
Colombia	3	Geologist	A		
Costa Rica	1	Research hydrologist	D	1	Ground-water photogeology.
Ecuador				1	Geology.
				1	Hydrogeology.
Guyana				1	Librarianship.
				1	Hydrologic data collection and analysis.
				1	Cartography.
Jamaica	3	Hydrologist	D	1	Surface water.
	1	Biologist	D		
Panama				1	Hydrologic data.
Paraguay	1	Geologist	D		
Peru	2	Geologist	D		
	1	Hydraulic engineer	D		
Trinidad and Tobago	1	Geologist	D		
Venezuela	1	Electronic technician	D		
	1	Research hydrologist	D		
West Indies				1	Ground water.
			Africa		
Canary Islands	2	Hydrologist	D		
Congo				1	Mining and geology.
Egypt				1	Geophysics.
				1	Geochemistry.
Ethiopia	3	Hydrologist	D		
	1	Cartographic technician	D		
Ghana				1	Hydrology and geophysics.
Kenya	2	Hydrogeologist	C		
Liberia	15	Geologist	A	3	Geology.
	3	Geophysicist	A		
	2	Cartographer	A		
	2	Cartographic technician	A		
	1	Administrative assistant	A		
Morocco	1	Hydrogeologist	C		
Nigeria	1	Ground-water hydrologist	D		
Somali Republic				1	Geology; geochemistry; geophysics.
South Africa				1	Microprobe analysis.
Sudan				1	Hydrometeorology.
				2	Hydrology.
Tanzania				2	Hydrology.
Zambia	1	Hydrologist	C		

Table 3.—*Technical assistance to other countries provided by the U.S. Geological Survey during fiscal year 1971*—Continued

Country	USGS specialists assigned to other countries			Scientists from other countries trained in the United States	
	Number	Type	Type of activity[1]	Number	Field of training
Near East-South Asia					
Afghanistan				1	Hydrology.
				1	Surface water.
Ceylon	1	Geologist	D		
	1	Research chemist	D		
India	2	Hydrologist	D	1	Water-resources development.
				1	Surveying and mapping photogrammetry.
				7	Soil and water management.
				8	Hydrology.
				2	Phosphates.
				1	Alluvial morphology.
				1	Nuclear geology.
				1	Sedimentation.
				1	Photogeology; topography.
				1	Production techniques in surveying, mapping, and printing.
				2	Hydrogeology.
				1	Drilling.
				1	Exploration for radioactive materials.
Iran	1	Geologist	D	1	Water-resources development.
Jordan				2	Ground water.
				2	Engineering geology.
Nepal	1	Engineering technician	C	2	Ground water.
	1	Chemist	C		
	1	Supervisory hydraulic engineer	C		
	1	Ground-water hydrologist	C		
Pakistan	8	Hydrologist	C	1	Ground water.
	1	Geologist	C	6	Hydrology.
				1	Geology; laboratory techniques.
				1	Phosphates.
				3	Geohydrology.
Saudi Arabia	15	Geologist	A	7	Geology.
	3	Geophysicist	A	1	Maintenance of buildings and air conditioners.
	3	Chemist	A	1	Chemistry.
	1	General services officer	A	1	Administration.
	1	Administrative officer	A		
	2	Cartographic technician	A		
	1	Geologic cartographer	A		
	1	Mathematician	A		
	1	Topographic engineer	A		
	1	Photogrammetrist	A		
	1	Computer scientist	A		
	5	Driller	A		
	2	Project assistant	A		
	1	Physical science administrator	A		
	1	Technical publications editor	A		
	1	Electronics technician	A		
Turkey	6	Geologist	C	3	Minerals exploration.
	2	Geologist	D	1	Spectroscopy.
	1	Research chemist	C	1	Geophysical instrumentation.
	1	Research physicist	C	1	Applied geochemistry.
	1	Photographer	C	3	Drilling.
	1	Driller	C	1	Cartography; topographic mapping.
	1	Cartographic technician	C		
	1	Ore beneficiation specialist	C		

Table 3.—*Technical assistance to other countries provided by the U.S. Geological Survey during fiscal year 1971*—Continued

Country	USGS specialists assigned to other countries: Number	Type	Type of activity[1]	Scientists from other countries trained in the United States: Number	Field of training
Far East-South Pacific					
Indonesia	8	Geologist	A	1	Chemistry of radioactive materials.
	2	Research chemist	A	1	Field, laboratory, and administrative geology.
	1	Geophysicist	A	1	Mineral economics.
	1	Photogeologist	A	1	Topography.
	1	Photographer	A		
	1	Cartographer	A		
Japan				1	Estuarine research.
Korea	1	Ground-water hydrologist	C	2	Mining and geology.
				1	Geochemistry.
				1	Water-data collection and evaluation.
				2	Ground water.
				1	Phosphates.
				1	Age determinations.
New Zealand	1	Research hydrologist	D	1	Isotope geochemistry.
				1	Crustal deformation.
Republic of China				1	Analytical techniques.
				1	Geochemical exploration.
				1	Land subsidence, ground water.
				1	Exploration for radioactive material.
Thailand	2	Research hydrologist	D	1	Hydrology—river basin development.
	1	Geologist	D		
	1	Driller	D		
Vietnam	1	Hydrologist	D	1	Surface-water techniques.
Europe					
Austria	1	Research hydrologist	D		
	1	First officer	D		
Denmark				1	Mineralogy.
France	4	Hydrologist	D		
	1	Geologist	D		
	1	Cartographic consultant	D		
Germany				1	Geophysics.
Greece				1	Electronics in nuclear logging.
Italy				1	Volcanology.
Poland	1	Research hydrologist	D	1	Water quality.
				1	Hydrology.
				1	Water-resources development.
Spain	1	Geologist	D	1	Surface- and ground-water resources.
Switzerland	2	Geologist	D		
	1	Research physical scientist	D		
	1	Photogrammetric consultant	D		
Union of Soviet Socialist Republics.	2	Geologist	D		
Yugoslavia				1	Sedimentation.

[1] A, broad program of assistance in developing or strengthening earth-science institutions and cadres; B, broad program of geologic mapping and appraisal of resources; C, special studies of geologic or hydrologic phenomena or resources; D, short-range advisory help on geologic or hydrologic problems and resources.

SUMMARY BY COUNTRIES

Unless otherwise stated, the work described below was sponsored by the U.S. Agency for International Development and the government of the cooperating country through its earth-sciences institutions.

ARGENTINA

Ground water in the Pampean region of western Buenos Aires Province

In August 1970, J. D. Winslow and S. N. Davis completed a ground-water reconnaissance of western Buenos Aires Province to evaluate salt-water–fresh-water interface problems, mechanics of ground-water recharge and movement, and ground-water discharge by evapotranspiration in numerous salt-encrusted playas. The study was undertaken in support of a joint U.S. National Academy of Science and Argentine National Council of Scientific and Technical Investigations research project to develop a methodology for improving the fresh-water yield from the prevailing water-poor Pleistocene sand-silt aquifer in the pampean region of central Argentina. Detailed studies of typical selected areas to determine relations between soil infiltration capacity, rates of ground-water recharge, and local availability of fresh ground water in the aquifer were recommended.

BRAZIL

Campo Formoso, Bahia, chromite deposits

D. C. Hedlund (USGS), and Jairo F. C. Moreira, Antonia C. F. Pinto, and Jose Carlos V. G. da Silva of the Companhia de Pesquisas de Recursos Minerais (CPRM) continued field study of the chromite mines and deposits of the Campo Formoso district in north-central Bahia. All mines are open pits within a 1 to 2 km wide outcrop belt of metamorphosed ultramafic rock that extends about 20 km along the west side of the Serra de Jacobina. The Jacobina Group (Precambrian) overlies the ultramafic rock, but the depositional contact has been largely obscured by strong thrust faults.

The chromite deposits are stratiform. Typically the chromitite is occluded and net textured and in layers that are fairly regular and continuous where not disrupted by faulting.

Float containing detrital chromite has been found near the Coitizeiro mine and provides evidence for considerable erosion of the ultramafic layered intrusion prior to the deposition of the sandstone and shale of the Jacobina Group. Because of the substantial volume of chromite that was precipitated, it is assumed that the layered intrusive was of considerable thickness, possibly as much as 3,000 to 4,000 m thick. As much as three-fourths of the intrusive may have eroded away prior to thrust faulting.

Chromite has formed in three types of layers: as disseminations, as interstitial grains intergrown with lilac-colored kammererite to form net-textured ore, and as massive chromitite as much as 1.78 m thick. The stratigraphy of the chromitite layers has not been completely resolved, but in the vicinity of the Pedrinhas and Coitizeiro mines, minable layers are in a 60-m interval approximately 150 to 250 m above the base of the intrusive. Three to five chromitite layers within the 60-m interval are 0.30 to 1.78 m thick, and many layers measure from 1 mm to 0.30 m thick and show rhythmic layering.

Tungsten district of Rio Grande do Norte

R. H. Nagell completed a 2-yr study of the scheelite deposits of northeast Brazil in cooperation with geologists of the Departamento Nacional da Produção Mineral (DNPM) and CPRM to determine the geology, structure, and ore controls of the scheelite-bearing tactite zones. Most of the work was done at the Brejuí Mine–Barra Verde ore body near Currais Novos in Rio Grande do Norte. Four tactite beds in limestone near the contact with gneiss are the main scheelite producers in the mine. Substantial reserves of scheelite were estimated, and have an average grade of 0.7 percent WO_3 and 0.19 percent Mo as molybdenite. Only scheelite is recovered from milling operations.

An economic study of the scheelite mines and deposits in the district was made by R. W. Merwin, of the U.S. Bureau of Mines (USBM). Merwin has made recommendations to the DNPM regarding the establishment of a central ore-dressing mill on the Brejuí ore body; the mill would concentrate, in addition to the ore from the Brejuí ore body, as much as 1,000 tons per day of scheelite ore or semiconcentrate to be truck hauled from smaller mines or deposits as far away as 100 km. Flowsheets for the mill, prepared by R. N. Spencer (USBM), have been transmitted to DNPM.

Phosphate in central Minas Gerais

The phosphate-bearing rocks of Cedro do Abaeté and adjacent municipalities in west-central Minas Gerais have been studied by J. W. Mytton (USGS) and Fernando de Oliveira and Adamir Chaves (CPRM) since 1969. The major phosphate deposits are in a northeast-trending belt approximately 2 to 3 km wide and 30 km long of highly folded argillite and siltstone, reportedly of earliest Cambrian age, and tentatively assigned to the Serie Bambuí. Minor phosphate rocks are in remnants of flat-lying Cretaceous arenaceous and tuffaceous rocks that uncomformably overlie the argillite and siltstone.

The phosphate forms lenticular bodies parallel to northeast-trending fold axes. They are as much as 500 m long, and outcrop widths range from 1 to 20 m because of repetition of strata. The maximum thickness, however, is no more than 8 m and averages 2 to 3 m. The bodies are lenticular in outline along strike and also at depth. Some lenses contain more than 30 percent P_2O_5, but the average content is about 15 percent. The predominant phosphate mineral is carbonate fluorapatite.

The fine texture of the host rock, problems of mineral indentification, lack of definable sedimentary structures, and the intense folding in the area make it difficult to correlate the phosphate lenses and to establish the depositional environment and history of the phosphate and its host rocks. A major part of the phosphate, however, occupies fractures, and it is very possible that all the phosphate may be epigenetic. Trace-element data from samples collected and studied by J. B. Cathcart indicate an origin somewhat other than normal marine. X-ray diffraction patterns of these samples show the carbonate fluorapatite of the fracture fillings to be closer to the pattern for igneous fluorapatite than the carbonate fluorapatite of the groundmass.

Reserves of phosphate-bearing rock in the Bambuí, based on trenching and core drilling, are less than one million metric tons. Because of the lenticularity, low tenor, and small tonnage, the phosphate deposits of the Bambuí are not considered to be economic, except possibly for local consumption.

Platiniferous chromitite in Goiás

R. W. White (USGS), and Jorge Motta and Vanderlei A. de Araújo (CPRM) have reported (p. D26–D33) a discovery of platinum metals in chromitite in the Tocantins complex near Niquelândia in Goiás. Platinum tenor found to date is low but is high enough to encourage further investigation; if sufficient high-platinum chromitite were found, possibly platinum could be economically extractable along with chrome.

Chromitite, restricted to the ultramafic zone of the complex, is in scattered lenses within an area of 500 by 8,500 m. The distribution of the chromitite is irregular and discontinuous, both laterally and longitudinally. The principal deposit is at the head of Corrego da Fazenda, where a chromite-bearing zone can be traced for 1,900 m; another chromite-bearing zone in the Angiquinho area is 500 m long.

Massive chromitite forms tabular, lenticular, or podiform masses that thin, pinch out, or grade laterally into disseminated material. A few lenses of chromitite exceed a meter in thickness, but more commonly they are 2 to 30 cm thick. The chromitite typically is restricted to discontinuous tabular chromite-bearing zones 2 to 5 m thick, in which small chromitite masses are enclosed in 50 to 90 percent of gangue consisting of weathered serpentinized dunite or peridotite. The chromite is of the typical podiform type, and it is of a composition that may be suitable for manufacture of refractories or chemicals.

In four channel samples of chromitite from the ultramafic zone of the Tocantins complex, total platinum metals range from 0.16 to 3.42 ppm. Platinum constitutes 61 to 84 percent of the total, the remainder consisting of equal amounts of palladium and rhodium. A specimen of pyrrhotite-bearing harzburgite from the same area contains 0.125 ppm total platinum metals, of which 62 percent is palladium and the remainder platinum.

In the Tocantins complex, several thousand tons of inferred reserves of platiniferous chromitite may be present as fragments in the residual soil over the largest chromite-bearing zone, and a few thousand tons are inferred per meter of depth in situ. The low grade and the small reserves indicate that the deposit probably is unfavorable for economic utilization primarily as a source of platinum metals. Furthermore, duplicate analyses of the two richest samples show them to be quite homogeneous relative to typical platinum-bearing samples; consequently some or all the platinum metals could be dispersed in solid solution in the chromite, in which case a chemical process would be required for their complete recovery. Possibly the platinum metals could be recovered as a byproduct of the production of sodium bichromate from the chromite.

CENTO

CENTO training

The fifth annual Central Treaty Organization (CENTO) training course in geologic mapping, mineral exploration, and mineral evaluation was conducted in Iran under the direction of E. H. Bailey. Other instructors were M. P. Nackowski (University of Utah) and J. W. Barnes (University of Wales, College of Swansea, U.K.); during part of the program additional assistance was provided by Professors Abbas Kimyai and Dr. Fereydoon Saraby (University of Tehran) and Mehmet Yildiz (Maden Tetkik ve Arama Institusü of Turkey). Fourteen graduate geologists or mining engineers from Turkey, Iran, and Pakistan took part in the field training. The program was supported logistically by the Geological Survey of Iran, and financially by the Multilateral Technical Cooperation Fund of CENTO, British Overseas Development Agency, and the U.S. Agency for International Development.

The field training took place at the Kushk zinc-lead mine, operated by Bafq Mining Co., in a remote area 150 km east of Yazd, Iran. The postgraduate participants learned modern field techniques used in mapping, sampling, and evaluating the potential of a mineralized area. Their field maps and reports were of immediate value to the mine operators, and a more detailed report covering all aspects of the study is being prepared for publication by CENTO.

CHILE

Analysis of nitrate ores

B. F. Grossling (r1002) and G. E. Ericksen collaborated in making electronic computer studies of a suite of 815 chemical analyses of soluble salines in nitrate ores, representing monthly averages of ores treated by the two largest nitrate plants in Chile from 1932 to 1967. A package statistical program, STATPAC, of the U.S. Geological Survey was utilized to: (1) estimate the abundance of sodium not reported in the analyses, (2) determine the soluble-insoluble ratio, (3) calculate the basic statistics, and (4) investigate the correlation between the saline constituents. The statistical average composition of the soluble salines in these nitrate ores, estimated to be a close approximation of the average of Chilean ores as a whole, is as follows (in weight percent; the standard deviation is given in parentheses): NO_3, 6.29 (±0.60); Cl, 4.58 (±1.26); SO_4, 10 (±3.16); IO_3, 0.060 (±0.012); ClO_4, 0.028 (±0.012); B_5O_9, 0.50 (±0.11); Na, 6.90 (±1.19); K, 0.73 (±0.36); Ca, 1.81 (±0.55); Mg, 0.46 (±0.28); percentage of solubles, 31.36 (±5.69). The analyses do not give the true abundance of salines of low solubility such as anhydrite, which commonly make up several percent of the nitrate ore, nor of several other saline ions present in minor or trace amounts which together generally do not make up more than a percent or two. Tables have been prepared for the significant correlations between relative abundances of the constituents, which give a clue to the mineralogical composition of the nitrate ore. The analysis of these correlation studies is under way.

Digital-computer modeling of the Rio Aconcagua valley

A digital model was prepared by O. J. Taylor for the stream-aquifer system of a typical short reach of the Río Aconcagua valley in central Chile. Simulation of irrigation, using ground water pumped from the valley-fill aquifer, resulted in slight reductions in ground-water storage and streamflow during the irrigation season. The main effect of ground-water withdrawals on streamflow occurred about a year after the wells were pumped. The time delay is a function of the transmissivity of the valley-fill aquifer.

COLOMBIA

Regional structural synthesis

E. M. Irving completed a synthesis of geological and structural information resulting from the 5-yr cooperative program (1964–70) with the Instituto Nacional de Investigaciones Geológico-Mineras; the data indicate that the three-pronged northernmost Andes formed around the margin of the Guyana shield of northern South America near its juncture with the oceanic Pacific crust. The shield was consolidated into a craton during the Guyanese or Tran-Amazonas orogenic episode about 2,000 m.y. ago, and served as a platform for the deposition of epicontinental and miogeosynclinal deposits during much of Phanerozoic time. During the Paleozoic Era a eugeosynclinal trough developed around the northwest periphery of the craton; at the close of the Paleozoic, an orogeny involving the other edge of the craton and its superadjacent sediments, and the deposits in the pericontinental eugeosyncline, produced the ancestral Central Cordillera. During the Mesozoic Era a second pericontinental eugeosyncline formed outside the upper Paleozoic fold belt, and at the close of the Mesozoic it too was folded to form the Western Cordillera. During early Tertiary time, a large intracontinental basin developed east of the Central Cordillera in which thick Cenozoic deposits, approximately equivalent to those of the Barinas Basin in southern Venezuela, accumulated. In middle Tertiary time the third prong of the Colombian Andes, the intracratonic Eastern Cordillera, rose along marginal sharp folds, high-angle reverse faults, and locally along strike-slip faults. The three prongs thus are distinctive geologically and formed at quite different times. Late Tertiary epeirogenic uplift added considerable altitude to the ranges. Granitic intrusives of diverse ages are present: Precambrian, Late Ordovician, late Paleozoic, Jurassic-Triassic, Late Cretaceous, and Oligocene-Miocene. Volcanism is evident in all rock groups from the Precambrian to the present.

Mineral deposits

During a 2-month assignment W. C. Prinz reviewed four undeveloped iron deposits in Colombia. He recommended further work at Ubala, Department of Cundinamarca, aimed at identifying iron reserves that will be attractive for exploitation.

J. B. Cathcart (r0416) reviewed the progress of phosphate exploration during a 3-month study. Phosphorite deposits of probable economic importance have been found in the sandy facies of the Upper Cretaceous miogeosyncline in the Sogomosa area. In a potentially economic deposit in the Conejera syncline, the main phosphorite bed is 2 to 3 m thick. Reserves may be about 50 million metric tons.

Cathcart also visited the native sulfur mine at Puracé Volcano, and studied the aluminous laterites at Popayán. The laterites are mainly along the summits of interfluve ridges developed upon Pliocene–Pleistocene volcanic detritus (Popayán Formation), over an area of about 2,400 km^2. The alumina-enriched zones are from 2 to 4 m thick. Even though preliminary analyses range between 30 and 40 percent Al_2O_3, this represents a very large potential source of alumina; further mineralogical study is needed to determine possible beneficiating methods.

ETHIOPIA

Earth-sciences library

T. O. Nowlin completed his second tour in Ethiopia where he acted as advisor to the Imperial Ethiopian Ministry of Mines. The Ethiopian Geological Survey Department (EGSD) was recently (1968) established in the Ministry, and the existing earth-science library required a modernized system of cataloguing and expansion. Under Nowlin's direction the EGSD library instituted a system for procurement of publications and exchange of publications with foreign agencies; established an expandable cataloging system for books and maps; cataloged its accessions; and reorganized its working procedures, rules, and instructions.

INDIA

Ground-water reconnaissance in central India

C. L. R. Holt, Jr., in late 1970, completed a reconnaissance of four representative hydrogeologic areas proposed for detailed ground-water investigations in central India. They include an alluvial tract in Madhya Pradesh, a coastal sedimentary zone in Gujarat, an area of plateau basalts in Maharastra, and a tract of weathered crystalline rocks in Mysore. The results of these investigations will have wide application through central India where early ground-water development for irrigation is essential for India's expanding food requirements.

INDONESIA

Mapping program

Mapping in progress by Geological Survey of Indonesia (GSI) geologists, under the direction of K. B. Ketner, and field checking of unpublished manuscript maps is leading to a better understanding of the Tertiary stratigraphy and structure of the central part of west Java. Emphasis is being given to designating and describing type sections of formations and to the solution of problems of identification, correlation, and nomenclature of rock units.

Reconnaissance in west Sumatra by M. R. Klepper and K. B. Ketner and in west Sulawesi by Ketner and D. E. Wolcott indicates areas for extending GSI's quadrangle and small-scale mapping program into regions where the geology is poorly known, but is more varied and complex and generally more favorable for major mineral discoveries than on Java.

Compilation of a tectonic map of Indonesia by W. B. Hamilton (r0050), with contributions from Indonesian geologists, is now nearing completion. It is contributing a keener insight to the development of the Indonesian archipelago and will benefit program planning and the search for minerals. The Indonesian region is found to record continuous plate interactions during Late Cretaceous and Cenozoic time: the Indian Ocean-Australian plate has moved steadily northward and the western Pacific plate westward, and these converging motions have been accommodated in a constantly changing array of subduction zones, oroclines, and rifted oceanic basins in Indonesia and surrounding regions.

Geothermal investigations

Integration, evaluation, and field checking of previous geologic studies with findings of recent geochemical (A. H. Truesdell), resistivity (Group Seven, Inc.), and photogeologic investigations (Liek Pardyanto, Geological Survey of Indonesia), has led L. J. P. Muffler to the conclusion that the Dieng Mountains of Central Java may contain significant resources of geothermal energy. The area of interest is a fumarole and hot-spring field in the heart of an extensive Quaternary (and possibly uppermost Tertiary) andesitic volcanic pile. Phreatic activity continues to the present. The principal thermal activity centers around lineaments that probably reflect deep-seated fault zones; geophysical work indicates a pronounced resistivity low in this area, and preliminary geochemical work suggests that the fumaroles and hot springs are surface expressions of a near-neutral chloride hot-water system (at least 200°C) at depth.

KOREA

Hydrogeologic reconnaissance of the Han River basin

J. T. Callahan, reporting on a recently completed 5-year ground-water investigation of the Han River basin, notes that exploratory drilling in bedrock formations indicates that (1) granite is the most consistently productive aquifer, (2) drilling in limestone thus far has been less than successful, and (3) sandstone aquifers can yield from 500 to more than 1,000 m^3/day to individual wells. He estimates ground water in storage in bedrock and alluvial aquifers to be about 62,000 million m^3. Also, annual pumpage of 3 percent of storage will meet projected ground-water requirements from the basin for the year 2001.

LIBERIA

A major objective of the U.S. Geological Survey's cooperative program with the Liberian Geological Survey (LGS) is to construct a series of national maps necessary to the continued development of the country. As a prelude to the compilation of 1:250,000-scale geological and geophysical map series, a shaded-relief, form-line topographic base map is being constructed. Concurrently, joint LGS-USGS geological teams are conducting studies leading to an economic appraisal of Liberia's mineral resource potential as a means of encouraging investment in, and development of, Liberia's resources.

Possibly of equal or greater value, however, are the project's institutional development activities. Participant and intern training is producing a Liberian staff nucleus competent in the fundamental technical skills of the earth sciences. With the trained personnel, the data derived from the geologic and geophysical studies, and the facilities developed through the cooperative program, the LGS will be able to continue the important functions of a national geological survey organization after completion of the cooperative program.

Country-wide aeromagnetic and aeroradioactivity survey data carried along north-south lines 800 m apart and 150 m above mean terrain are being used in compiling the 1:250,000-scale reconnaissance geologic map series. J. C. Behrendt (USGS) and C. S. Wotorson (LGS) find that iron-formation, amphibolites, and large mafic intrusions have associated high amplitude (250–18,000 gammas) magnetic anomalies, whereas zones of diabase dikes are revealed by magnetic anomalies of less than 250 gammas amplitude. Rock foliation directions are indicated by trends of short-wavelength magnetic anomalies. The total-count gamma radiation data correlate with the "felsic nature" of the various terranes: large areas of granitic rocks can be differentiated and separated from more mafic granulites, amphibolites, iron-formation, and unmetamorphosed sedimentary rocks.

Geochronology of crystalline basement rocks

Three major age provinces have been recognized by G. W. Leo, R. W. White (USGS), and P. M. Hurley (r1418) and H. W. Fairbairn (Massachusetts Institute of Technology) as a result of whole-rock Rb-Sr dating and field studies, and of geophysical interpretation by J. C. Behrendt and C. S. Wotorson. Lithologic, structural, and metamorphic differences characterize the three provinces. The Liberian age province of about 2,700 m.y. occupies much of the interior of western and central Liberia and extends into Sierra Leone and northwestern Ivory Coast. The Eburnean age province of about 2,000 m.y. is in eastern Liberia and extends into Ivory Coast. The Pan-African age province of about 550 m.y. occupies a coastal belt extending from central Liberia northwesterly through Sierra Leone.

Tectonic map

J. C. Behrendt reports that the aeromagnetic, total gamma radioactivity, and gravity data, combined with geologic mapping observations, have been used to construct a preliminary tectonic map of Liberia. The map shows foliation trends, approximately delineates the boundaries between the Liberian, Eburnean, and Pan-African age provinces, and indicates major structural zones containing diabase dikes. Rock foliation and tectonic structural trend directions are northeastward in the Liberian age province, curve east-northeastward to north-northeastward in the Eburnean, and northwestward in the Pan-African. Linear residual magnetic anomalies 20 to 80 km wide and 200 to 600 gammas in amplitude cross the entire country and extend into Sierra Leone and Ivory Coast. The long-wavelength anomalies, only slightly modified by Eburnean and Pan-African thermotectonic events, can be correlated with similar broad anomalies reported by others in Sierra Leone, Ivory Coast, and the Guyana shield areas of South America.

Heavy-mineral investigations

Preliminary results of a systematic study by Samuel Rosenblum (USGS) and S. P. Srivastava (LGS) of heavy minerals in 57 beach sand samples can be correlated with results of geochronologic and geologic investigations. The Eburnean province is characterized by aluminous minerals, low ilmenite, and high monazite and zircon; the Liberian province provides moderate amounts of these minerals plus locally abundant kyanite; and the Pan-African province is characterized by abundant ilmenite, pyroxene, monazite, and zircon. Radioactivity highs along the beach are due to concentrations of zircon and monazite, and are tentatively correlated with anomalous aeroradioactivity highs in two areas in eastern Liberia. Gradual westward decrease in monazite content indicates westward-moving longshore currents. Relatively abundant sillimanite in eastern beaches indicates that high-grade metamorphic rocks are to be found inland.

Diabase dikes

Dikes of tholeiitic diabase are widespread in Liberia. Detailed mapping in the eastern part of the country, reconnaissance mapping, and an airborne magnetometer survey of the entire country have delineated three broad zones within which swarms of dikes are concentrated.

The coastal and central zones trend northwesterly, parallel to the coast. The third zone, in the interior part of the country, trends predominantly east. Only the central zone is well defined across Liberia, as reported by R. W. White (r2513).

The diabases in all three zones contain widespread accessory quartz in graphic intergrowths with alkalic feldspar. Normative quartz is shown by calculations of rock analyses. Labradorite and augite are the predominant minerals, whereas magnetite and lesser ilmenite are the magnetic phases. Some dikes have small amounts of sulfides, and sparse amounts of primary native copper are found rarely in dikes in the central and northern zones.

G. B. Dalrymple has completed 42 K-Ar age analyses on samples from 20 hypabyssal diabase units in the two zones parallel to the coast. The diabase dikes and sills that intrude sedimentary rocks near Monrovia give concordant ages in the range 173 to 193 m.y., whereas the dikes that intrude older Precambrian crystalline rocks inland give apparent ages ranging from 220 m.y. to 1,200 m.y. Furthermore, within these inland dikes, ages from the same hand sample or rock unit may be discordant. The cause of the anomalous ages from the inland dikes is not known, but it may be extraneous argon from the Precambrian crystalline rocks. Results of a concurrent investigation of the paleomagnetism of the diabasic dikes and sills undertaken by C. S. Grommé, R. W. White, and Wilfred Davis suggest that all the tholeiitic rocks sampled are the same age and are Jurassic. On available evidence the best estimate of the age of the diabases in the two zones parallel to the coast is 173 to 193 m.y.

Gravity survey

Data collected in a regional gravity survey have been interpreted by J. C. Behrendt (r0937, r2501) and C. S. Wotorson. A 50- to 60-mgal positive Bouguer anomaly correlates with mafic granulites in the Monrovia region, where the gradient is too steep to be entirely due to crustal thickening at the continental margin, and may be related to tectonic activity associated with basins on the continental shelf. The only major break in this positive anomaly along the entire coast of Liberia is over granitic gneiss adjacent to (and presumably underlying) the only onshore basins on the Liberian coast. Local negative Bouguer anomalies exist over two Cretaceous basins in the coastal area. The high mean free-air anomaly of +22 mgal (exclusive of the coastal anomaly) suggests that the approximate 200-m mean elevation of Liberia is not compensated, at least over the Liberia region. A linear regression, showing a significant correlation of elevation with Bouguer anomaly, has a zero elevation intercept of +18 mgal, again indicative of an isostatic anomaly. The standard deviation of ±14 mgal from the Bouguer anomaly—elevation regression line indicates the amplitude range of local geologic anomalies. These include a 30-mgal anomaly over an ultramafic intrusion near Juazon and an approximate 30-mgal anomaly associated with a mafic intrusion at Cape Mount. A crustal model computed to fit observed marine and land Bouguer anomalies shows an abrupt thickening at the continental margin with several kilometers of sedimentary rock on the continental slope, uplifted dense lower crustal rocks at shallow depths beneath the continental shelf southeast of Greenville, and a high mean crustal density.

Mineral-resource investigations

Mapping and petrologic study of the metasedimentary sequence in the Wologizi Range by R. W. White has disclosed a biotite zone surrounded by concentric garnet, staurolite, and sillimanite zones of metamorphism. Metamorphic parageneses in oxide- and silicate-facies iron-formations are similar to those reported by H. L. James in iron-formations in northern Michigan. Variations in grain size of quartz and magnetite in the iron-formations likewise correspond to the variations in metamorphic grade. A large tonnage of oxide-facies iron-formation is inferred, but the bulk of it is confined to the biotite zone, and consequently the grain size is very fine.

Samuel Rosenblum (USGS) and S. P. Srivastava (LGS) have summarized the metamorphic geology, mineralogy, and reserves of a rock-phosphate deposit near Bambuta, about 75 km north of Monrovia. The phosphate minerals are aluminous at the surface (variscite and augelite), but are mainly ferriferous in depth (strengite and barrandite). Sufficient phosphate rock is inferred to make this deposit a potential mineral resource. Minimum reserves are estimated as 1 million tons containing about 32 percent P_2O_5; further exploration is in progress by the concessionaire.

Samples of submarine sediments collected from the continental shelf, 4 to 15 mi off Cape Mount, contained as much as 88 wt percent of shell fragments. About 66 percent of one sample was shell fragments greater than 35 mesh (0.5 mm). A simple vacuum-dredge and trommel recovery operation on such materials could possibly supply a local lime industry.

Topaz has been identified in alluvial samples collected from beaches southeast of Monrovia. Elongate colorless grains as much as 3 carats in weight were identified by optical means and confirmed by X-ray diffraction pattern. The well-frosted grains are clear inside and may be of gem quality.

Note.—See p. A231 for information on international assistance programs in topographic mapping in Liberia.

PAKISTAN

Electric analog studies of flow to wells in the Punjab aquifer of West Pakistan

M. J. Mundorff and G. D. Bennett (both USGS) and Masood Ahmad[185] (West Pakistan Water and Power Development Authority) performed a series of experiments with a steady-state electric analog model simulating a cylindrical segment underlying the plains of the Punjab region of West Pakistan. The experiments indicated that, under aquifer conditions prevailing in the Punjab region, the distance-drawdown method for determining permeability will give results within an error of 10 percent or less, provided that at least one piezometer or observation well is within a few feet of the pumped well and no piezometer or observation well is used that is more than 100 feet from the pumped well.

[185] Mundorff, M. J., Bennett, G. D., and Ahmad, Masood, 1972, Electric analog studies of flow to wells in the Punjab aquifer of West Pakistan: U.S. Geol. Survey Water-Supply Paper 1608-N. [In press]

PERU

G. E. Ericksen (r0144) and George Plafker (r2517) spent four weeks during June and July in Peru studying the geological effects of the May 31, 1970, earthquake in west-central Peru. They worked with J. F. Concha from Peru, and collaborated with a special UNESCO team formed to make a preliminary study of the effects of the earthquake. Their study included an assessment of the extent of damage in several areas, description of geologic hazards to reconstruction, and recommendations for reconstruction.

REPUBLIC OF CHINA

Black monazite study

Combined results of a review by W. C. Overstreet of published and unpublished data on black monazite from Taiwan, and of analyses of one sample of the monazite by J. W. Adams, J. M. Nishi, B. F. Leonard, and I. C. Frost disclose that of the five possible modes of origin suggested for oolitic gray to black monazite, two are more probable for the black monazite from Taiwan. These are: (1) formation as an authigenic sedimentary mineral, or (2) formation from authigenic sedimentary rhabdophane through heat and pressure of regional metamorphism. Less probable concepts for the origin of the oolitic black monazite are formation as: (1) original igneous accessory mineral, (2) weathering product of igneous monazite, or (3) contact metamorphic mineral in the aureole of cassiterite-bearing granitic plutons.

Features indicative of a sedimentary or sedimentary/metamorphic origin include porphyroblastic texture with inclusions of quartz, mica, carbon, and rare iron sulfide, oolitic shape, larger average grain size than associated with yellow monazite of different chemical composition, low specific gravity, low hardness, very low percentage of thorium, and unusually high percentage of europium. These features seem to preclude the possibility that this black monazite is derived directly from granitic rocks or other plutonic rocks exposed in the borderlands of the Tertiary basin of Taiwan.

An adequate explanation for the origin of this oolitic black monazite is needed to guide possible additional exploration. If the explanation points to authigenic sedimentary origin in sites close to the present beaches, then these sites could be appraised with only a small additional effort. If a sedimentary/metamorphic origin is indicated, considerable additional search for the source would be needed upstream from the beaches. If the black monazite, like the yellow, proves to be in the Tertiary sediments, the ultimate source may not be on Taiwan at all. Should exploration by stream sampling lead into phyllitic terrain in the central range, the black monazite may be in phyllite or low-grade schist in concentrations favorable for mining. Owing to the abundance of insoluble inclusions in the black monazite, however, special conditions would be required to market it.

This work is a byproduct of the UNESCO/ECAFE Second Seminar on Geochemical Prospecting Methods and Techniques, that was held in Ceylon in 1970.

SAUDI ARABIA

Geologic mapping

The U.S. Geological Survey's agreement with the Kingdom of Saudi Arabia for the period September 1969 to September 1972 calls for detailed geologic mapping of 25½ 30-minute quadrangles in Precambrian rocks. As of March 1971, approximately 50 percent of the fieldwork had been completed.

In the Wadi Yiba quadrangle, R. W. Bayley mapped a belt of limestones and shallow-water clastic rocks 5 to 6 km thick—the Wadi Yiba Formation—that trends north through the quadrangle, and the basement complex on which they were deposited. Subsequent to deposition, these rocks were folded, intruded by syntectonic granite, faulted, and intruded again by posttectonic plutons. One of these, a massive ring dike of mafic and ultramafic rocks near Lakathah, is being explored for concentrations of titaniferous magnetite.

R. G. Coleman, working in the Khaybar quadrangle, has found that the basement rocks consist of high-grade paragneiss and orthoamphibolites. Anatexis is extensive within the basement rocks and produces migmatites and autochthonous granites. A major unconformity separates the basement from overlying mafic lavas and pelitic and carbonate sedimentary rocks that have undergone regional metamorphism to the greenschist facies. Juxtaposition of greenschist facies rocks on top of the old high-grade terrane without retrogression suggests possible Precambrian thrusting. Extensive folding of both the basement and overlying low-grade metamorphic rocks was accompanied by syntectonic invasion of small granite plutons into antiforms and layered gabbros into synforms. Whole-rock K-Ar ages of about 600 m.y. on the layered gabbros gives a minimum time for this orogeny. A posttectonic quartz monzonite batholith crosscuts all previous units. Numerous dikes and faults that transect all units including the posttectonic granite suggest north-south attenuation of the crust some time during the Phanerozoic.

Mapping by W. J. Greenwood in the Aqiq and Jabal Ibrahim quadrangles indicates that metagraywackes and pillow basalts overlie a high-grade metamorphic basement of amphibolite-biotite gneiss and folded granitic rocks. The gneisses show old structural and metamorphic elements as well as the effects of superposed greenschist metamorphism and folding. The contact between the metagraywackes and pillow basalts and the basement rocks is probably a thrust. Postmetamorphism faulting, including major west-dipping thrusts, has further complexly juxtaposed rocks of different metamorphic histories. The postmetamorphism faults indicate a strong east-west directed compression which may be of Precambrian age.

Mapping by D. G. Hadley in the Sahl al Matran quadrangle in northwest Arabia reveals the presence of an angular unconformity at the base of the Shammar Formation. The dip of the paleoslope of this erosional-depositional surface is now known, but the thickness and coarseness of the conglomerate indicate that the northern part of the Arabian shield was uplifted during Precambrian time.

Studies of metallic minerals

Conrad Martin has found sparse but persistent copper, lead, and zinc minerals in the vicinity of the ancient Mukahal mine in the Wadi Yiba quadrangle. These minerals and sporadic small amounts of gold, silver, and molybdenum are in the lowermost 100 m of shallow-water clastic and carbonate rocks of the Wadi Yiba Formation (Precambrian). Random surface sampling indicates average copper, lead, and zinc contents of 0.02, 0.09, and 0.15 percent, respectively. Much higher but more local concentrations, mostly in the form of secondary copper and zinc minerals and complex lead oxides, are found along shear faults and fracture zones. In the clastic rocks these local concentrations are generally the sites of small ancient copper mines. Channel samples from the pits averaged 3.70 percent Cu, 0.20 percent Pb, 0.81 percent Zn, 0.02 oz Au and 0.92 oz Ag per ton. The mineralized belt has a strike length of 40 km in the Wadi Yiba quadrangle, and it extends for some distance to the south. Although the Mukahal area does not hold much economic promise, the possibility of finding more favorable mineralization elsewhere along this belt cannot, as yet, be ruled out.

The Wadi Yiba prospect, 19 km southeast of the Mukahal mine, has been explored with nine diamond drill holes. Below about 100 m, the holes are barren. Sparse secondary copper mineralization is widely dispersed in the Wadi Yiba Formation in joints, faults, and fractures, especially in metavolcanic and carbonate rocks. Several sets of accordant ridges, benches, hanging valleys, and remnants of perched gravel beds mark the levels of ancient pediments. The mineralization is mostly below a surface marked by the tops of a set of north-trending flat ridges about 40 m above the present wadi bottoms. The mineralization probably resulted from the weathering of sparsely copper-bearing detrital material blanketing a surface of low relief defined by the accordant ridges and remnants of perched conglomerate. Copper leached from this material traveled down the slope of the bedrock into faults and fractures, preferentially infusing the most amenable rock types. This would account for the wide areal distribution of copper, its limited vertical range, and its somewhat greater concentration in the more competent metavolcanic rocks. This last tendency gives a superficial impression of stratigraphic control.

Titaniferous magnetite has been found in a complex bowl-shaped pluton located near Lakathah, about 90 km east of Al Qunfudhah. The pluton is about 10 km in diameter with about 1,300 m of vertical relief. It has a pyroxenite core about 500 m wide and 1,500 m long, an intermediate gabbroic layer about 2 km wide, and a dioritic to syenitic peripheral layer 1 to 3 km wide. Studies by Conrad Martin indicate that the titaniferous magnetite is concentrated in the pyroxenite core and in several peripheral zones. Float samples contain as much as 16.7 percent TiO_2 and 45 percent iron. The TiO_2 content of core samples from a 123-m diamond drill hole ranges from 2.5 to 8.7 percent and averages 5.7 percent. The iron content ranges from 8 to 30 percent and averages 16.5 percent. Pyrite, chalcopyrite, and pyrrhotite range as high as 0.1 percent throughout most of the core. The titanium and iron have formed together chiefly in a single spinel phase concentrated predominantly in the central core. In the peripheral part the titaniferous magnetite forms lenses as much as 5 m wide and 54 m long. A variable amount of titaniferous magnetite, however, is found in all lithologies.

Except for the outer syenite and the massive pyroxenite core, the pluton is conspicuously layered. Layers range in thickness from a few millimeters to tens of meters and form discontinuous arcuate zones as much as several hundred meters long. Magnetite-pyroxene-rich layers are within a few tens of meters of the peripheral syenite. A narrow layer of albitite is midway between the core and the peripheral part. Anorthosite and anorthoclase rock locally form narrow conformable layers. The structure of the core is obscure and consists of huge blocks that are diversely oriented and bounded by narrow zones of recrystallized fine-grained mylonitic rock. The intrusion is partly roofed by syenite.

To explain the origin of the complex on usually accepted lines poses some challenging problems. A simple history of intrusion, cyclical in situ differentiation, crystallization, and convection with associated crystal cumulates does not fully explain the field relations. A view of the complex as an extended complex orbicule may reveal a fruitful approach to the problem. Further study is warranted in light of the possible economic potential of the pluton and the basic geologic problems it presents.

Tectonic map of the Arabian Peninsula

On the basis of a large amount of published and unpublished geologic and geophysical data, largely from oil companies, geophysical surveys, and geologic mapping by the U.S. Geological Survey, G. F. Brown is evaluating current concepts of tectonics in order to compile a tectonic map of the Arabian Peninsula. These concepts include overthrusting of oceanic or mantle material in the Oman, and the ophiolitic suite and related rocks forming the bulk of the mountain range from Jebel Akdar northward. Within and near the eastern edge of the Precambrian shield in western Arabia, thrusting or a high-angle reverse fault extending northward is associated with mantle and oceanic suites that have ridden from the east over continental metamorphosed rocks. W. J. Greenwood has mapped a similar parallel structure 420 km to the west, but with the thrust rising eastward out of the Red Sea in opposition to the eastern fault. Such overlaps may be interpreted as resulting from collision between two plates during Precambrian time, although the evidence is not clear. Certainly east-west compression was followed by shear along transverse faults that cross the shield with sinistral movement—that is, the northeastern side of the transverse faults has moved northwestward with respect to the southwestern flank. Horizontal displacement along these faults ranges from about 5 to 25 km as measured by French geologists of the Bureau de Récherches Géologiques et Minières (BRGM), geologists of the Japanese Geological Survey, and geologists of the U.S. Geological Survey. The farthest movements are in the older rocks, indicating that relative displacements may be used as a check of the geochronology.

An important adjunct to the tectonic map concerns the age and composition of lava outpourings over the western third of the peninsula; the eruptions were intermittent during Tertiary and Holocene time. Utilizing K-Ar total rock determinations, 45 isotopic ages range from Holocene to Eocene (0 to 41.8±3.0 m.y.), exclusive of one sample which gave an anomalous date of 60.9 m.y. Thirteen ages group around early Miocene (≈25 m.y.), nine samples average about 12 m.y., nine average 6 m.y., and eight are less than 3 m.y. These preliminary values point to major volcanic activity in late Oligocene—early Miocene time when the Red Sea rift appears to have opened extensively for the first time. Subsequent volcanic activity occurred during late Miocene, and at the beginning and end of the Pliocene, with intermittent activity up to the present as shown by historical records and by the nearly uneroded nature of some ash and cinder cones.

Chemical analyses indicate that these lavas and associated feeder dikes are all alkalic. This contrasts with the tholeiitic or subalkalic and oceanic nature of lavas of similar ages dredged from the center of the Red Sea rift and from many samples from the African side of the Red Sea.

Geophysical investigations

Geophysical investigations by V. J. Flanigan and G. E. Andreasen in Saudi Arabia include the interpretation of existing aeromagnetic and radiometric data in terms of geological significance, supplemental surveys including airborne gamma-ray spectrometry surveys of selected areas, and the preparation of a comprehensive magnetic map of the Arabian peninsula. Detailed interpretation of existing aeromagnetic data of the Arabian shield at scale 1:100,000 has provided considerable information on structural configuration of anomaly-producing rock units, their areal extent, attitude of interface of units of differing magnetic susceptibility, and depth of burial. Synthesis of these data at a smaller scale provides a basis for a more regional geologic interpretation. Aeromagnetic maps for most of the Arabian shield are being compiled at a scale of 1:500,000 as a step toward making a 1:2,000,000-scale total intensity map of the Arabian shield. Multicolor maps are being prepared by Andreasen and A. J. Petty of the Southern Najd quadrangle and the shield portion of the adjoining Southern Tuwayq quadrangle in order to distinguish relative levels of magnetic intensity that are not readily noticed in black and white.

Long, linear negative anomalies paralleling the Red Sea trough are produced by near-vertical dikes polarized in a direction opposite to the earth's present field. The reversed anomaly trends may have been caused by intrusions concurrent with intrusions that produced the axial trough anomaly. Elsewhere in the Arabian shield where long linear magnetic features are observed, the anomalies are normally polarized and are produced by fault contact between rocks of differing magnetic properties.

Airborne gamma-ray spectrometry surveys totaling more than 12,000 traverse kilometers were flown of selected areas of the Arabian shield. Although analysis of the digital data is just beginning, it is evident that gross count, potassium, uranium, and thorium have a close correlation with mapped rock units as well as with magnetic anomalies. How effective these surveys will be in mapping and prospecting pediment areas is not yet clear. A digital system has been developed to provide computer-generated profiles and contour maps using an automatic dataplotter.

Layered gabbros in southwestern Saudi Arabia

Layered gabbros of two distinct ages have been discovered on the Precambrian shield of southwest Saudi Arabia by R. G. Coleman and G. F. Brown. Numerous lopolithic layered gabbros north of the Asir Mountains have radiometric ages from 415 to 702 m.y. Miocene (20–24 m.y.) layered gabbro occupies a steep flexure on the east margin of the Red Sea depression. Gabbros of both ages exhibit cumulate layering that represents large volumes of basaltic liquid fractionation. The old lopolithic gabbros may be the northern extension of the ancient African rift zone that developed before separation of the Nubian and Arabian plates. The Miocene layered gabbro formed during the early development of the Red Sea depression and was later tilted toward the Red Sea axis. Post-Miocene diabase dikes now cut the layered gabbro and in turn are covered by Pleistocene alkali basalt flows in this eastern flexure.

Note.–See p. A231 for information on international assistance programs in topographic mapping in Saudi Arabia.

SICILY

J. G. Moore and Motoaki Sato participated in a collaborative study of volcanic processes, with emphasis on volcanic gases at Etna Volcano in eastern Sicily. This study was the first to be undertaken in volcanology under the France–United States exchange program. Teams from France, Italy, Great Britain, and the United States participated. Experience gained by Moore and Sato from the scientific discoveries of the expedition and from observations by them of advanced techniques and equipment used by the other teams aid in the Survey's volcanic hazards program in the United States.

THAILAND

Potash investigations

As a result of field and analytical studies, R. J. Hite has determined that the Cretaceous halite-bearing strata in the Khorat and Sakhon-Nakhon basins are favorable as targets for potash exploration. The uppermost of an unknown number of marine evaporite cycles, from base to top, consists of red siltstone, green siltstone, anhydrite, halite, green siltstone, and red siltstone. No carbonate rock is present; the missing carbonate facies is probably present in lateral equivalents of the cycle where the evaporite basin connected with the sea. X-ray fluorescence of core samples of halite from holes drilled near Chaiyaphum shows 30 to 150 ppm Br. From the base of a 335-foot-thick halite bed, the bromine distribution profile shows a slow upward increase; in the upper third, bromine content increases rapidly, suggesting that during the final stage of halite deposition, restriction of circulation between ocean and basin was intensified, and salinity increased markedly. During this period of high salinity, potash may have been deposited. An initial phase of widely spaced core-hole drilling has been recommended.

Geohydrologic reconnaissance in Khorat Plateau region

According to D. A. Phoenix, test drilling has been sufficient to prove the presence of rock salt at relatively shallow depth (300–600 feet) in the subsurface and also the presence of ground water of poor chemical quality in several areas of the Khorat Plateau of northeast Thailand. Because of anticipated irrigation of some of these areas by diversions from the Mekong River and its tributaries, concern has been expressed about alteration of the natural hydrologic regimen by applied water and possible resulting saline contamination of streams and ground water. Detailed geohydrologic studies have been proposed in the Chaiyaphum area of the Khorat Plateau, which is planned for early irrigation, to evaluate the critical hydrologic variables involved in irrigation application versus increases in water salinity.

TURKEY

The cooperative mineral exploration program of the Mineral Research and Exploration Institute (MTA) of Turkey and the

U.S. Geological Survey continued through 1970 with two significant economic developments. An iron deposit near Hasançelebi (see index map) in central Turkey, discovered by drilling after geologic mapping and geophysical surveys, is being evaluated. Investigations, including geochemical prospecting, in cooperation with Etibank, a government-owned mining corporation that operates the Maden mines, indicate

that additional copper deposits are present in the Ergani-Maden copper mining district in southeastern Turkey.

Hasançelebi iron deposit

The geology of a 210 km^2 area between Hekimhan and Hasançelebi about 120 km southeast of Sivas was mapped in 1968 and 1969 by H. S. Jacobson (USGS) and Zeki Kendiroǧlu, Celil Özdemir, Reşat Boǧaz, Osman Önder, and Nafis Gurel (MTA). Airborne magnetometer surveys were made by MTA personnel. One mine was operating in the western part of the mapped area, and small iron deposits were known to exist elsewhere.

After the geologic and geophysical surveys, a test hole was drilled at the site of a magnetic anomaly near Hasançelebi. The magnetite content of 11 core samples was determined from Davis tube tests by J. W. Pressler (U.S. Bureau of Mines) and Ali Akar (MTA) to range from 37 percent to 62 percent and to average 48 percent. Amounts of silica and titanium were low, and deleterious elements P, S, and As were present in trace amounts. Core drilling and laboratory analyses of the cores continued through 1970 in evaluation of the deposit.

According to Jacobson and his colleagues in MTA, magnetite in the area is irregularly distributed in veins and disseminations in metasomatized mafic rocks. Veins range in thickness from a few centimeters to 7 m, and many follow walls of dikes. Jacobson considers the deposits to be related to the intrusion of a syenite (?) batholith which underlies much of the area. Metasomatism of the mafic rocks during the syenite intrusion resulted in the formation of new minerals, including scapolite, and in the release of iron from some silicates and iron oxides in the invaded rocks. The iron was transported by hydrothermal solutions and redeposited as magnetite and minor hematite.

Ergani-Maden copper deposits

The results of cooperative geochemical prospecting and geologic mapping by the U.S. Geological Survey and MTA in the Ergani-Maden copper district of southeastern Turkey indicate additional copper deposits.

The Maden ("mine" in Turkish) copper deposits are in southeast Turkey about 75 km northwest of Diyarbakir and near the town of Ergani. Copper, reportedly, has been mined there for at least 4,000 yr, and Maden has been one of the most productive copper areas in Turkey. Two areas were mapped and sampled by A. E. Weissenborn (USGS) and Ömer Öner and Metin Segün (MTA).

The two areas studied are northwest and southwest of the main Ana Yatak deposit and mine. Two hundred eighteen geochemical samples were collected and analyzed by spectrographic methods for total copper. Two anomalously high areas were found in each of the two mapped areas. The strongest, in the area northwest of Ana Yatak, is indicated by 25 samples which contained 100 to 400 ppm copper. Background count was considered to be about 100 ppm. Drilling the four anomalies was recommended on the basis of the geochemical anomalies, pending completion of geophysical surveys.

Previous work by W. R. Griffitts and J. P. Albers (USGS) and Ömer Öner (MTA) indicated that the ore bodies are in a north-dipping sequence of eugeosynclinal sedimentary and volcanic rocks of probable Eocene age that have been intruded by a mafic igneous complex composed in part, or largely, of serpentinized diorite. Ore is largely massive sulfides, mainly pyrite and chalcopyrite, in flat-lying bodies not far above the intrusive. Most ore bodies are in chlorite rock, most of which Griffitts and colleagues conclude is altered mudstone of the eugeosynclinal sequence.

UNION OF SOVIET SOCIALIST REPUBLICS

Plate tectonics

W. B. Hamilton (r1282) analyzed Soviet geological and geophysical maps and reports to develop a history of the Ural Mountains and the other Paleozoic orogenic terranes between the Russian and Siberian platforms in terms of plate tectonics. He found that the geologic indicators of various tectonic and magmatic belts related to continental-margin and island-arc subduction zones of different ages support the concept that the two continental platforms approached each other across an ocean whose floor disappeared beneath the continents until they collided in Permian time. Analogous continental collisions may be recorded wherever "eugeosynclinal" terranes lie within the present continents.

ZAMBIA

L. E. Bidwell reported that receding runoff during the annual 6- to 7-month dry season makes systematic investigation of the surface-water and ground-water potentials a necessity in

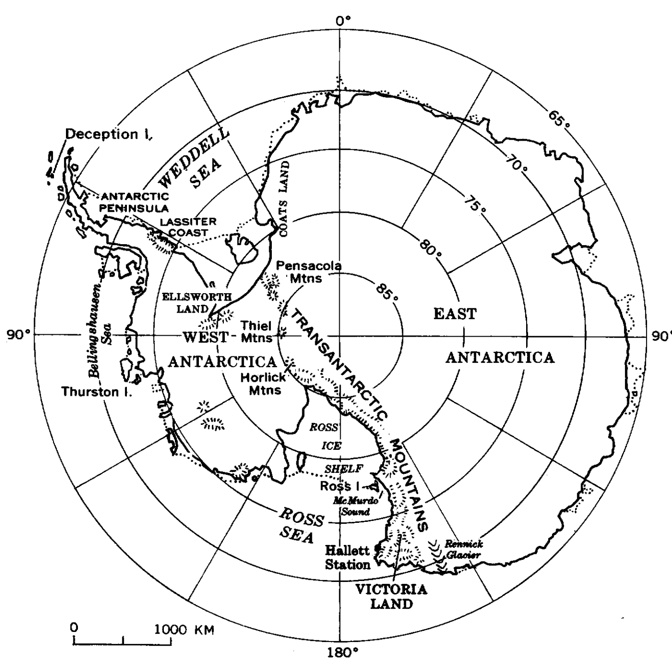
Zambia. Although the total annual precipitation ranges on the average from about 20 inches in the escarpment along the Zambezi River to more than 60 inches in areas near the Democratic Republic of the Congo border, most rainfall occurs during the months of December, January, and February. Mining, industrial, and urban growth in the Copperbelt and along the rail line, as well as improved living standards and farming practices in outlying villages and rural areas, tax the present water supply. To meet the increased demand for hydrologic data, training of Zambian technicians in collection of basic streamflow data and processing the records was conducted over a 2-year period ending in November 1970.

Analysis, computation, and compilation of all streamflow data collected in Zambia during the water years 1961–66 were completed and prepared for publication in the annual series of Hydrological Yearbooks in Zambia.

ANTARCTICA

Geophysical investigations

J. C. Behrendt has compiled Bouger anomaly and total magnetic intensity maps (scale 1:250,000) of areas mapped geologically by D. L. Schmidt and A. B. Ford in the Pensacola Mountains (see index map). Some local gravity and magnetic anomalies can be correlated with known geology and with some subice features. A linear regression analysis shows a relationship of Bouguer anomaly to bedrock altitude that probably indicates regional isostatic compensation. Over the Dufek mafic intrusion, the mean deviation of the data from the regression line is +26 mgal, and the maximum deviation is about +85 mgal, indicative of the mass effect of the intrusion.



Total-intensity magnetic anomalies over the Dufek intrusion have maximum amplitudes of about 2,000 gammas over the Forrestal Range; computed models fitted to magnetic data indicate that the magnetite in the intrusion is mostly concentrated in the upper part of the section, which is in the Forrestal Range. This is consistent with field geologic and laboratory measurements of magnetic properties and correlates with maximum Bouguer anomaly values.

Copper deposits

During the 1969–70 season, D. L. Schmidt and L. E. Brown found copper mineralization in plutonic rocks of the "Moats Nunataks" in the western RARE[186] Range, in the Lassiter Coast area, southeastern Antarctic Peninsula. Preliminary petrographic work by P. D. Rowley shows that the deposit, which locally contains ore-grade rock by U.S. standards, has many of the features of porphyry copper deposits. Fieldwork during the 1970–71 season disclosed a sequence of intrusive and related tectonic events in which sulfide minerals in shear zones resulted from crystallization of the third and youngest granodioritic pluton in the area. Detailed petrographic and geochemical studies are now being undertaken.

Permian plants in peat

A silicified peat deposit in central Antarctica reported by J. M. Schopf provided much new information about tissue construction of Permian plants of the *Glossopteris* flora. Studies suggest that the peat which gave rise to Antarctic Permian coal was similar to peat now forming in temperate climates. Egg cells, rarely preserved anywhere, show certainly that reproductive processes in some glossopterid plants were similar to those of contemporary fossils of northern countries, although in detail they are new.

The Thiel Mountains pallasite

Two fragments of pallasite, a relatively rare type of stony-iron meteorite, were found lying on ice in a moraine near the base of Mt. Wrather in the eastern part of the Thiel Mountains by A. B. Ford and R. W. Tabor (p. D56–D60). The two specimens, weighing a total of 28.6 kg, are the largest of four known meteorite finds on the continent, and are the only ones of pallasitic material. The two pieces were doubtless part of a single body before impact. The actual site of impact is not known. The freshness of the material, unusual for pallasites, probably attests to the extremely slow weathering rate in the arid, polar environment, rather than to recency of fall. The mineralogy is typical of that of Brezina's Krasnojarsk group of pallasites; the pallasite consists of rounded olivines (55.7 percent by weight) set in a metal reticulum of nickel-iron with minor amounts of troilite. X-ray diffraction studies show that the olivines more closely correspond to terrestrial plutonic than to volcanic types.

[186] Ronne Antarctic Research Expedition, 1946–47.

TOPOGRAPHIC SURVEYS AND MAPPING

OBJECTIVES OF THE NATIONAL TOPOGRAPHIC PROGRAM

A major function of the U.S. Geological Survey is to prepare and maintain maps of the National Topographic Map Series, covering the United States and its outlying areas. The several 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 mapping functions of the Geological Survey include the production of special maps and research and development in mapping techniques and instrumentation.

Procedures for obtaining copies of the map products of the Survey are given under "How to Obtain Publications" in the section "U.S. Geological Survey Publications" (p. A239–A241).

FEDERAL MAPPING COORDINATION

The responsibility for governmentwide coordination of federally funded domestic surveying and mapping activities was given to the Department of the Interior (and subsequently assigned to the U.S. Geological Survey) by the U.S. Bureau of the Budget (now Office of Management and Budget) revised Circular A-16.

Objectives of the coordination effort are: (1) to achieve a greater benefit to the Nation from a given mapping effort; (2) to reduce or eliminate duplication in the total national mapping effort; (3) to determine whether the mapping activities of each agency can practically or economically contribute to the National Topographic Map Series; (4) to develop the information necessary to permit the Geological Survey mapping effort to be as responsive as possible to the needs of other agencies; and (5) to increase the information resources of the Map Information Office of the Geological Survey so that it becomes a more effective single source for available maps and related data.

Significant progress has been made in efforts to achieve more effective coordination of federally funded domestic surveying and mapping activities. Initial liaison meetings have been held with 43 officially designated agency representatives. These meetings have established ready channels of communications with other agencies; determined agency and mapping needs; identified agencies that expend federal funds for mapping; provided information on mapping capabilities and the nature and volume of mapping, aerial photography, and geodetic control activities of each agency; and identified sources of cartographic products and data. The meetings also informed agencies of the functions and services of the Map Information Office and explained Geological Survey objectives and responsibilities in the mapping coordination effort.

Multiagency meetings have been held to explore development of a National Cartographic Information Center and joint procurement of high-altitude photography. Technical briefings and training have been conducted for other-agency representatives.

MAPPING ACCOMPLISHMENTS

Quadrangle map coverage of the Nation

General-purpose topographic quadrangle map coverage at scales of 1:24,000, 1:62,500, 1:63,360 (Alaska), and 1:20,000 (Puerto Rico) is now available for about 84 percent of the total area of the 50 States, Puerto Rico, the Virgin Islands of the United States, Guam, and American Samoa. Included in this coverage is about 7 percent of the total area which is not yet published but which is available as advance manuscript prints.

During fiscal year 1971, 1,324 maps were published covering previously unmapped areas equivalent to about 2 percent of the area of the 50 States and territories referred to above. In addition, 366 new maps at a scale of 1:24,000, equivalent to about 0.6 percent of the total area, were published to replace 15-minute quadrangle maps (1:62,500 scale) which did not meet present needs. Figure 6 shows the extent and location of the current topographic map coverage.

Map revision and maintenance

As maps become out of date, revision is necessary to show changes in the terrain and changes and additions to manmade features such as roads, buildings, and reservoirs. During fiscal year 1971, 978 general-purpose quadrangle maps of the 7½-minute series (1:24,000 scale) were revised. Most of these revised maps are in expanding urban areas or in States that have complete map coverage in the 7½-minute series. About 2,147 maps are currently in the revision program (fig. 7).

Map revision is usually accomplished by using a combination of photogrammetric, field, and cartographic procedures designed to update map content and to maintain or improve the

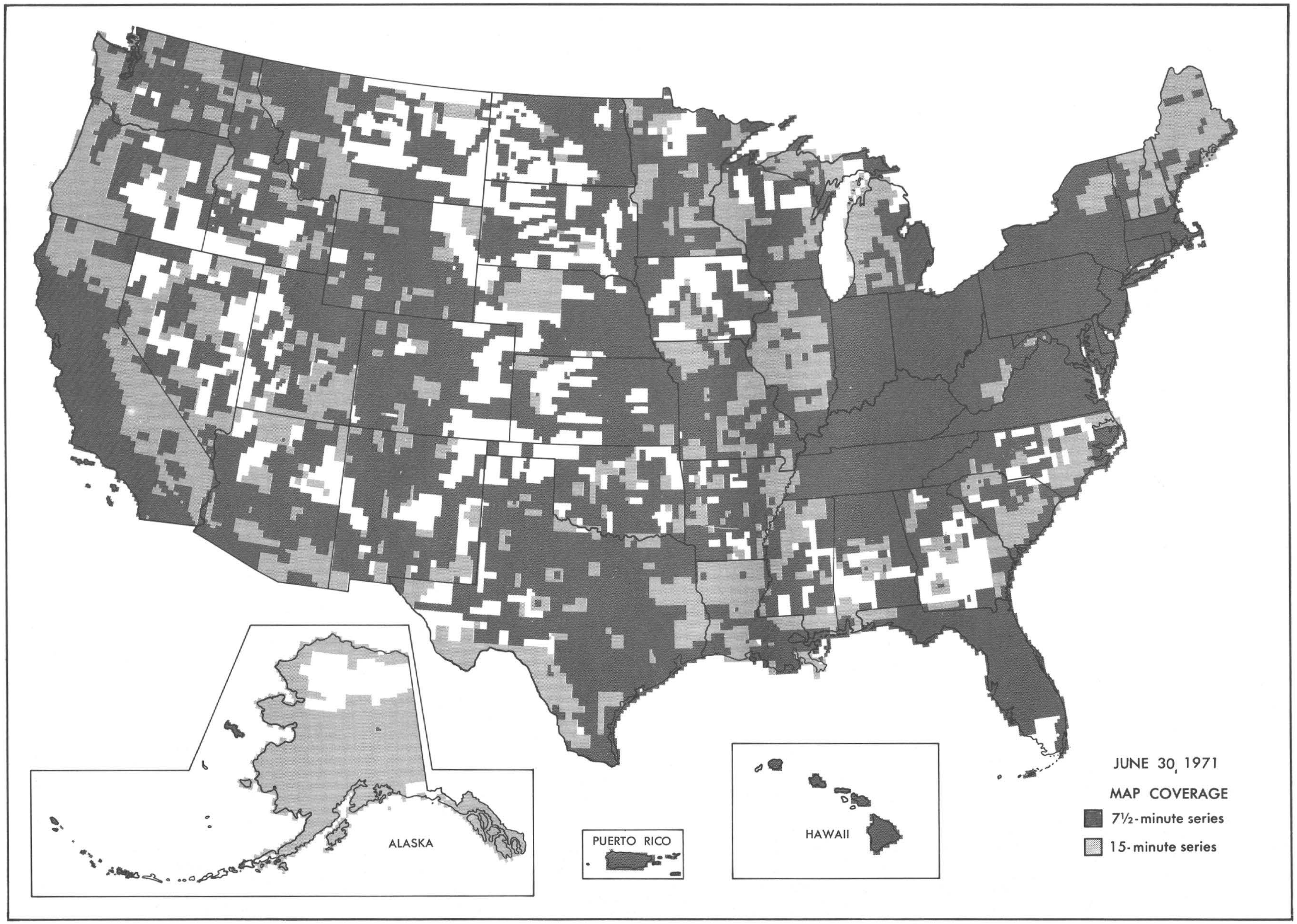


Figure 6.—Status of 7½- and 15-minute quadrangle mapping.

Figure 7.—Revision in progress, 7½- and 15-minute series topographic maps.

original accuracy of the map. An important step toward solving the problem of keeping maps up to date has been taken in the adoption of photorevision procedures. Information about changes in cultural and planimetric features that have occurred in an area is obtained from recent aerial photographs, and the new information is printed in purple on the revised map. Photorevision relies primarily on photointerpretation and is a low-cost, rapid-production method of updating maps.

Photorevision was applied first in the major metropolitan areas of the country, where rapid expansion and development have caused many maps to become out of date. Approximately 900 maps in urban areas, covering more than 50,000 sq mi, have been updated by photorevision, and the program is being expanded to include rural-area maps in need of revision.

In fiscal year 1971, 788 general-purpose quadrangle maps were reprinted to replenish stock.

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 (now U.S. Army Topographic Command–TOPOCOM). These maps are revised and maintained by the U.S. Geological Survey, with certain changes and additions to make them more suitable for civil use. The Geological Survey is replacing its Alaska Reconnaissance Series Maps at 1:250,000 scale with an improved series based on larger scale source material and on new photogrammetric compilations. Figure 8 shows revision 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. State maps of Alaska are published at scales of 1:1,584,000, 1:2,500,000, 1:5,000,000, and 1:12,000,000. A State map of Hawaii is being prepared for publication at 1:500,000 scale.

The series of State maps compiled according to modern standards now includes 48 maps covering 47 States and the District of Columbia (fig. 9). All these maps are published in planimetric editions; contour and shaded-relief editions are

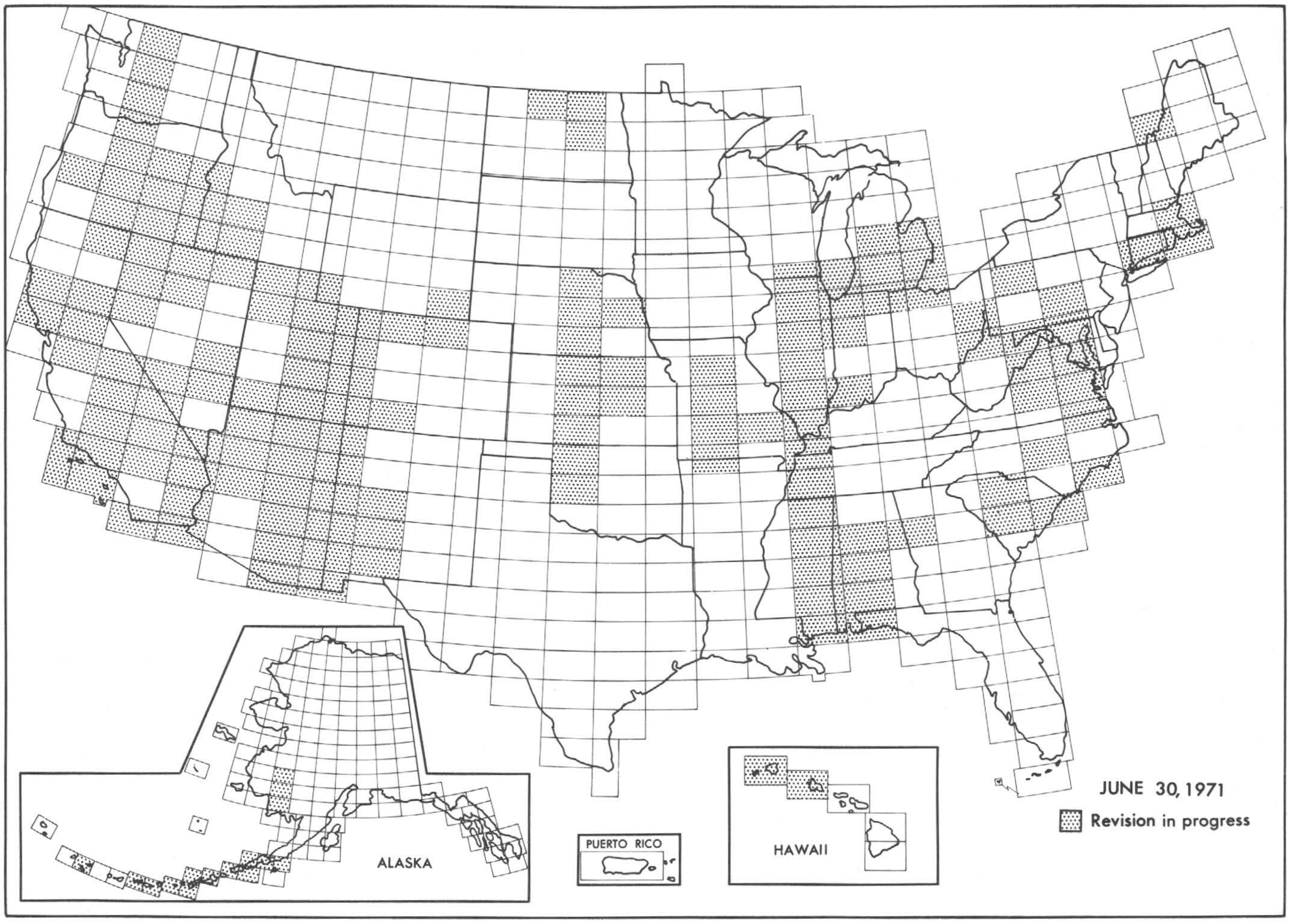


Figure 8.–Revision of 1:250,000-scale topographic maps.

also available for most of them. Fourteen of the maps, Arizona, Colorado, Illinois, Indiana, Maryland-Delaware, Massachusetts-Rhode Island-Connecticut, Michigan, Mississippi, Missouri, New Hampshire-Vermont, New Jersey, Ohio, Oklahoma, and Virginia are being revised. Other States are covered by an earlier series, also shown in figure 9.

National-park maps

Maps of 43 of the 214 national parks, monuments, historic sites, and other areas administered by the National Park Service have been published. 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 in the general-purpose quadrangle series. Published maps in the national-park series include:

- Acadia National Park, Maine
- Badlands National Monument, S. Dak.
- Bandelier National Monument, N. Mex.
- Black Canyon of the Gunnison National Monument, Colo.
- Bryce Canyon National Park, Utah
- Canyon de Chelly National Monument, Ariz.
- Canyonlands National Park, Utah
- 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.
- Glen Canyon National Recreation Area, Utah-Ariz.
- Grand Canyon National Monument, Ariz.
- Grand Canyon National Park, Ariz.
- 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 Park, Ariz.
- Rocky Mountain National Park, Colo.

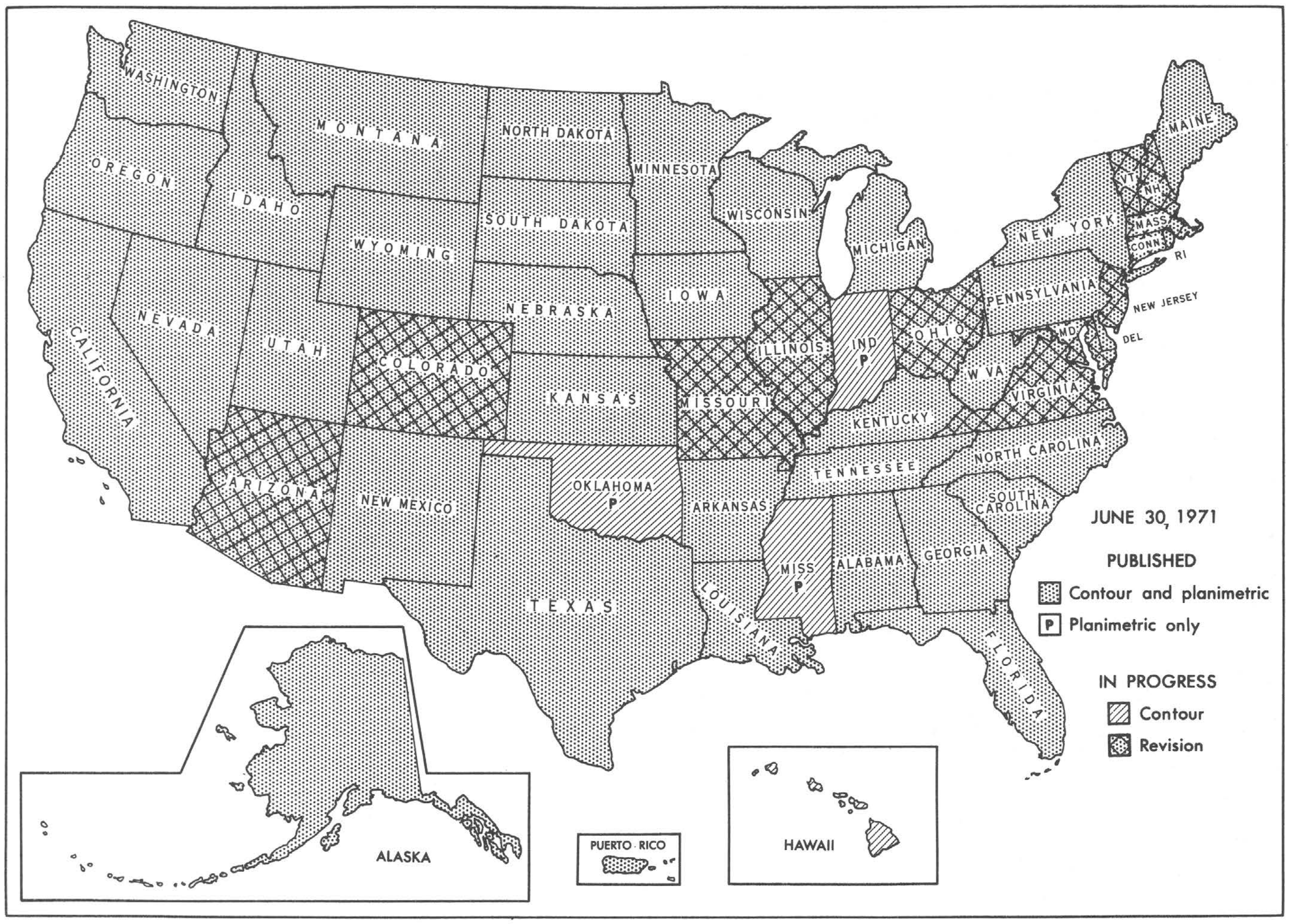


Figure 9.—Status of State maps.

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

Maps of the Acadia, Grand Teton, and Shenandoah National Parks and the Dinosaur and Great Sand Dunes National Monuments are being revised.

Million-scale maps

The worldwide million-scale series of topographic quadrangle maps was originally sponsored by the International Geographical Union and designated the International Map of the World on the Millionth Scale (IMW). Twenty of the 53 maps required to cover the conterminous United States have been produced.

From 1955 to 1959, the U.S. Army Map Service (now U.S. Army Topographic Command–TOPOCOM) published 27 maps of the conterminous United States and 13 maps of Alaska in a military series at the scale of 1:1,000,000. Although these maps do not meet the IMW specifications in all respects, they are recognized by the United Nations Cartographic Office as provisional editions in the IMW series (fig. 10).

Two of the maps, Hudson River and San Francisco Bay, are no longer available as IMW maps, but the areas are covered by maps in the military series. Maps of both the IMW and the military series are available for Boston, Chesapeake Bay, Hatteras, Mississippi Delta, Mount Shasta, and Point Conception. In addition, the American Geographical Society published the Sonora, Chihuahua, and Monterrey maps; and

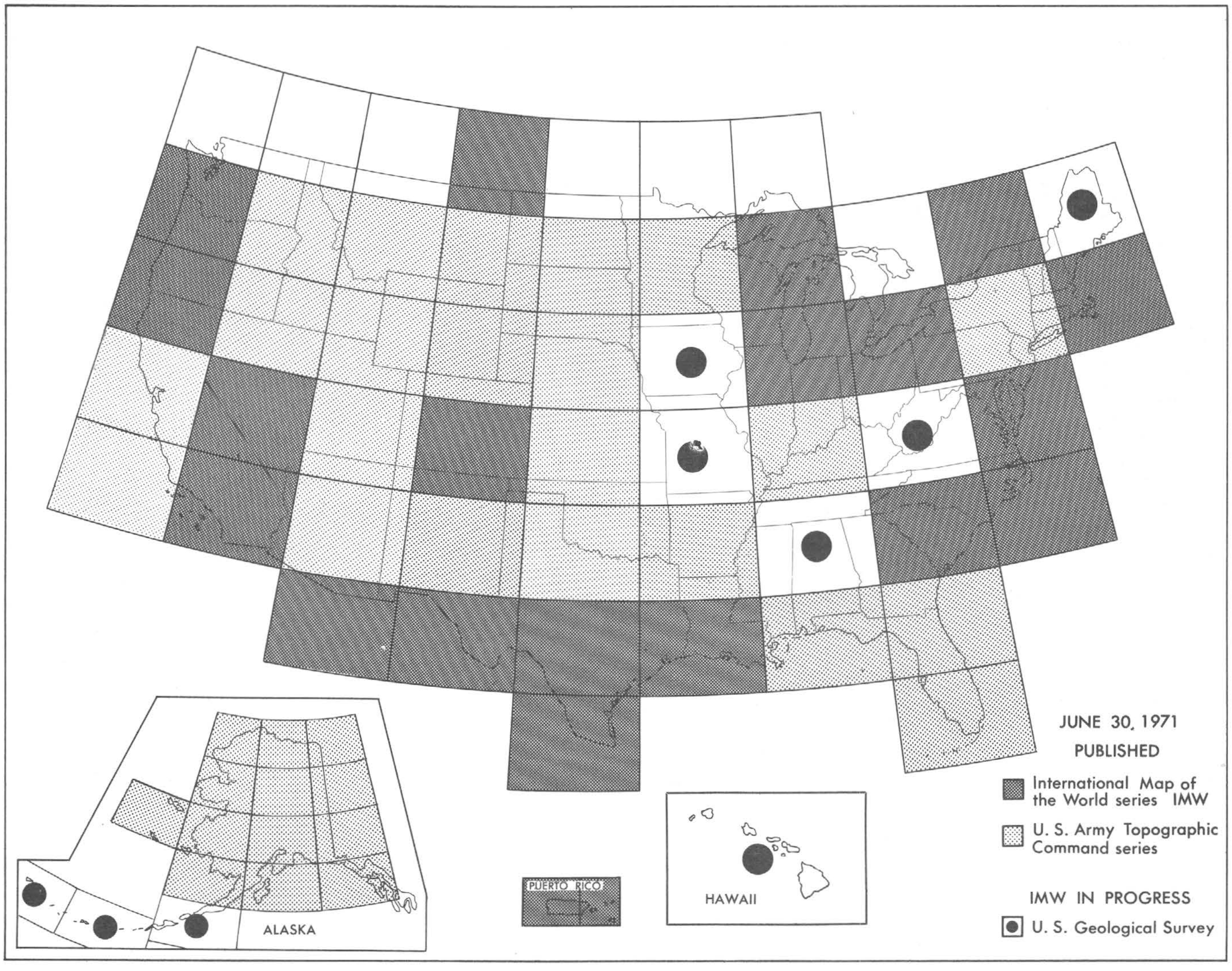


Figure 10.–Status of 1:1,000,000-scale topographic maps.

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 TOPOCOM.

Work in progress includes nine new maps: Andreanof Islands, Attu Island, Blue Ridge, Cold Bay, Des Moines, Hawaii, Lookout Mountain, Ozark Mountains, and Quebec.

Orthophotomapping

Orthophotomaps have been established as the standard 1:24,000-scale publication for many areas where conventional cartographic symbolization cannot adequately portray existing detail. Orthophotomapping is particularly effective for swamps, desert, coastal plains, and other areas of low relief and sparse culture.

Experimentation to determine the utility of an interim orthophotomap product has been carried out on a limited basis. Orthophotoquads—orthophotomosaics or orthophotographs in map format with limited cartographic treatment—have been prepared for the San Francisco Bay area, Lake Tahoe Basin, and the Indian Creek project in southern Nevada.

Thirty standard orthophotomaps have been published at 1:24,000 scale. In addition, 22 experimental orthophotomaps have been prepared for areas of varying physical characteristics, and experimental editions have been printed for 13 of these. There are currently 499 quadrangles in the program for standard 1:24,000-scale orthophotomap publication.

MAPPING IN ANTARCTICA

The U.S. Geological Survey continued to assist the National Science Foundation in its U.S. Antarctic Research Program (USARP) by assigning four field engineers and a cartographer for the 1970–71 austral field season. The field engineers were part of an eight-man Geological Survey field party that continued topographic and geologic reconnaissance mapping in the Lassiter Coast area of eastern Ellsworth Land. Although their primary project was to establish mapping control in the Lassiter Coast, they also conducted engineering surveys in support of other disciplines and activities. The cartographer, headquartered at McMurdo Station, was assigned to photographic liaison duty with the U.S. Navy.

Topographic field operations

E. G. Schirmacher, R. F. Whiting, A. I. Malva-Gomes, and R. L. Johnson established map control for an area of approximately 7,500 sq mi by expanding the 1969–70 survey northward from the Wetmore Glacier astronomic station to 73° south latitude and between 62° and 65° west longitude. Traveling by motor toboggan, they completed 145 miles of electronic traverse, monumented 10 primary stations, and intersected 36 secondary stations. The four engineers completed three additional surveys to aid other scientific investigations. They established three geodetic positions at Williams Field for use in a test and evaluation of an inertial navigational unit by the U.S. Navy. In the Wright Valley, they assisted a Russian exchange scientist in his glaciological studies by determining relative positions of phototheodolite stations in the areas of Meserve and Lower Wright Glaciers. The Wetmore Glacier glaciological strain-net markers established in 1969–70 were also remeasured for P. L. Williams.

Aerial photography

No new cartographic aerial photography was obtained for the 1:250,000-scale reconnaissance topographic mapping program; however, F. S. Brownworth, program coordinator and technical adviser on aerial photography, supervised photography of the Wright-Taylor-Victoria Valley for the proposed 1:50,000-scale orthophotomapping project. He also supervised the special aerial photographic program for the Office of Polar Programs of the National Science Foundation, the USARP investigators, and the U.S. Navy.

All aerial negatives are on file at the Geological Survey Antarctic Map and Aerial Photography Library, Branch of Special Maps, 8300 Colesville Road, Silver Spring, Md. 20910.

Cartographic activities

The status of U.S. Geological Survey topographic mapping in Antarctica is shown in figure 11. Ten 1:250,000-scale maps covering 39,000 sq mi of northern Victoria Land were published completing the block coverage (65 maps) of the Transantarctic Mountains. Production is underway on 20 topographic maps at 1:250,000 scale, covering 108,000 sq mi of Marie Byrd Land, and one sketch map at 1:500,000 scale, covering approximately 56,000 sq mi of Palmer Land.

NATIONAL ATLAS

The National Atlas of the United States of America was published early in 1971. The Atlas was compiled as a reference tool of high quality for use by public officials, business and industrial organizations, libraries, educational institutions, and scholars throughout the world who seek information about the United States. The 431-page volume required 8 years of work and involved the cooperation of more than 80 federal agencies and numerous commercial firms, specialists, and consultants. It contains 336 pages of multicolored maps and an index with more than 41,000 entries. The following individual map sheets are available as sales items:

United States general reference
Physiography and physiographic divisions
Land-surface form
Classes of land-surface form
Tectonic features (Alaska)
Tectonic features (conterminous United States)
Geology
Distribution of principal kinds of soils: orders, suborders, and great groups
Potential natural vegetation of Alaska and Hawaii
Potential natural vegetation
Monthly sunshine
Annual sunshine, evaporation, and solar radiation

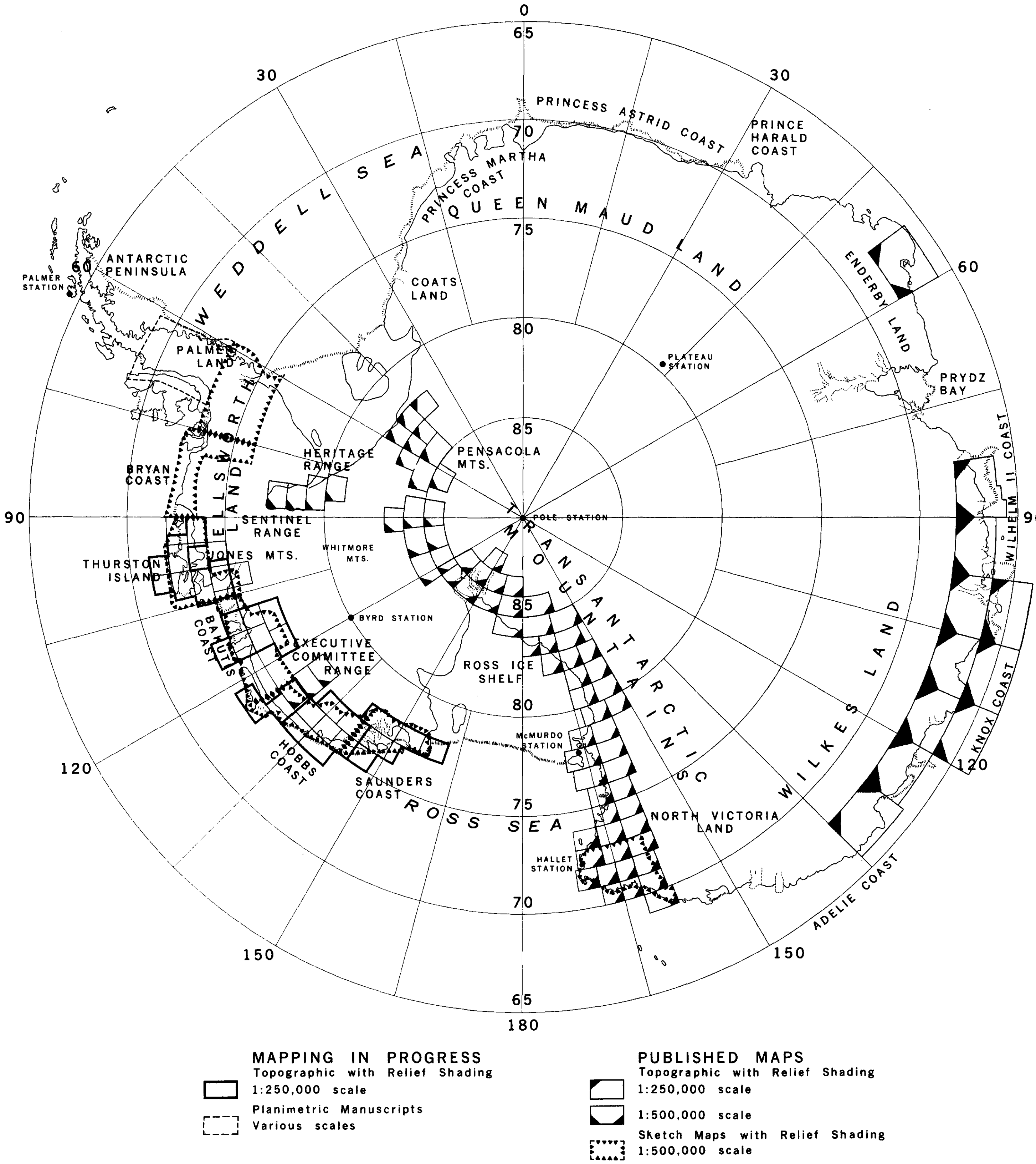


Figure 11.—Index map of Antarctica, showing status of topographic mapping by the U.S. Geological Survey as of June 30, 1971.

Monthly average temperature	Population distribution, urban and rural: 1960
Monthly minimum temperature	Federal lands
Surface water	Population trends
Principal uses of water	Congressional districts for the 91st Congress
Territorial growth	
Major forest types	

INTERNATIONAL ASSISTANCE PROGRAMS

Saudi Arabia

The U.S. Geological Survey is continuing to assist the Ministry of Petroleum and Mineral Resources of the Kingdom of Saudi Arabia in assessing the mineral potential of the Precambrian shield area of central and western Saudi Arabia. F. G. Lavery, photogrammetric specialist, and K. S. McLean, engineer geodetic specialist, are assigned to Saudi Arabia in support of the mineral investigations program. They manage the Ministry's aerial photography program and its photographic laboratory; establish horizontal and vertical control and compile small-scale base maps for geologic investigations, urban planning, and special projects; teach basic photogrammetry at the College of Engineering in Riyadh; and train counterpart personnel in photogrammetry and field surveys.

Liberia

The geological exploration and resources appraisal project in Liberia is a cooperative effort of the U.S. Geological Survey and the Liberian Geological Survey, under the sponsorship of the U.S. Agency for International Development (AID). In support of this program, the U.S. Geological Survey compiled 1:40,000-scale form-line maps covering the entire country. From these maps 1:250,000-scale geographic and geologic maps will be made in shaded-relief editions. Ten maps in the 1:250,000-scale series are in production.

Pan American Institute of Geography and History (PAIGH)

The U.S. Geological Survey provided technical and administrative support to the United States member of the Commission on Cartography and the chairman of the Committee on Topographic Maps and Aerophotogrammetry of the Pan American Institute of Geography and History, a specialized organization of the Organization of American States (OAS). Support activities included maintaining the files of the United States national section and translating letters and documents received primarily from Latin American members of the Commission on Cartography.

Training programs, visitors, and inquiries

Training in mapping operations was provided for participants from Brazil, England, Guyana, India, Indonesia, and Turkey. The participants were sponsored by the United Nations, U.S. Agency for International Development (AID), or special fellowship funds. Academic programs were arranged at selected universities for some of the participants. Visits were planned for distinguished scientists, engineers, and cartographers from 24 countries. Technical reports and publications, information on sources of equipment, instructions on new mapping techniques, and proposed solutions of mapping problems were provided to foreign countries in response to many requests.

RESEARCH AND DEVELOPMENT

FIELD SURVEYS

Developments in field equipment

Aluminum honeycomb material bonded on both sides with Fiberglas was investigated for constructing planetable boards and stadia rods for field surveys. Compared with wood, the material is lighter, more rigid, and less affected by moisture. A planetable board made of this material weighs about one-third less than a wooden planetable board. Prototype boards were made for evaluation in the field. The first cost per unit is high, but overall savings may be realized from longer service life and convenience.

Through the cooperative efforts of several agencies involved in surveying and mapping, including the U.S. Geological Survey, a new and improved instrument-packaging system was developed. The system comprises a common outer container and interchangeable shock-proof inserts fabricated to fit particular surveying instruments. By replacing the inserts, the same container can be used for different instruments. Tests show that the new packaging is far superior to conventional containers for protection against shipping damage. Some levels, for example, are shipped in wooden boxes with no material for reducing shock. Models of the new containers will soon be available for evaluation in field operations.

Surveying towers

U.S. Geological Survey engineers completed the design of an aluminum truck-mounted surveying tower that will have an extended height of 100 feet and a transporting length of 35 feet. The tower will be fabricated in six telescoping units, three each for the inner and outer towers. Double towers—one for instrument support, and the other for the observer—are necessary to permit the observer to move without disturbing the instrument during observations. The design has several characteristics similar to previous versions of the tower—welded unit construction, a ballast tank for extra stability, and a hydraulic lifter for raising and lowering. Shorter portable towers have been in operation for many years, but the extra length is needed for clear lines of sight in horizontal control surveys in timbered areas.

Driven-rod bench marks

Various methods have been used for joining sections of coppercoated rods which are driven deep into soil to provide stable support for bench-mark tablets. Crimped sleeves, threaded sleeves, soldered sleeves, and combinations of these have all been used with varying degrees of success. This year, experiments were conducted with drive pins for joining rod sections. The use of drive pins eliminates bulky sleeve couplings and thus reduces driving resistance and increases skin friction. The drive-pin method joins rods without the use of special equipment. In a tensile-strength test, a sample joint failed at 3,200 pounds, which is considered satisfactory. The critical factor in this method is precise fitting of the pins and holes.

Horizontal control

Portable Doppler receivers became available commercially in 1970, and considerable interest was generated in the cartographic community in establishing mapping control by Doppler satellite systems. In June 1970, the Geological Survey formed a Doppler System Work Group, which carried out a series of error analyses with encouraging results. A proposal was prepared for a Doppler translocation test in Antarctica in the 1971–72 season. Geometric factors are especially favorable for the system in the polar regions. Although many problems remain to be solved, the Doppler satellite system appears to have a promising future in horizontal control surveys.

Geodetic computations

The Master Control Program for computer processing of horizontal control survey data was completed. Any type of geodetic survey problem for topographic mapping can be solved with this program, usually in one run. The input is data from field surveys, and the output is plane coordinates and elevations in a form suitable for the photogrammetric phases of mapping. Functionally, the program consists of a main routine, a data file, and about 20 subroutines. Under operator control, the subroutines call, in turn, various other utility subroutines to carry out specific computations, for example, geodetic inverses.

PHOTOGRAMMETRY

The image correlator and measuring system

Correlating corresponding image points on overlapping photographs is a prerequisite for mapping by photogrammetric methods. An automatic image correlator built for the U.S. Geological Survey by the BAI Corp. has been improved and is now ready for operational use. It scans an annular area of a photograph, or other form of imagery, and develops an analog signal, or signature, which uniquely describes the scanned scene. The signature is then converted to digital form and stored on a punched card. Subsequently, the reference signature can be reestablished from the punched card, and a corresponding scene from other imagery can be scanned and correlated with micrometer accuracy.

A radial-amplification module, added to the image correlator, permits the shape of the annular scan ring on the image-dissector camera to be altered electronically. The ring diameter can now be varied to accommodate a considerable scale change. The scan ring can also be electronically stretched into an ellipse having the major axis in either x or y, and the annulus width can be held constant or differentially varied. This feature is expected to alleviate some of the scanning problems caused by anamorphic distortions in sloping terrain that is imaged from two or more widely separated perspective points. Some of the mechanical and electronic linkage for driving the monocomparator carriage is now being modified for easier pointing and positioning.

Aerotriangulation

A research project was started to investigate a method of increasing the production rate of fully analytical aerotriangulation and of decreasing the amount of vertical control required to constrain a block of photographs. The planned approach is to use super-wide-angle photographs to establish pass points for the wide-angle photographs used in map compilation.

The Louisburg and Castalia, N.C., 15-minute quadrangles, spanning 15 minutes of latitude and 30 minutes of longitude, were chosen as the project area. About 350 wide-angle photographs were taken in 10 flight strips at a flight height of 9,200 feet for compiling contours of 10-foot interval. About 30 super-wide-angle photographs with 60-percent overlap and 30-percent sidelap were taken at a nominal flight height of 22,000 feet for fully analytical aerotriangulation by the direct geodetic constraint method. About 100 super-wide-angle photographs were taken at a flight height of 11,200 feet as a safety or backup measure. Only 15 vertical control points will be used to constrain the 22,000-foot photographs. Pass points for the 9,200-foot photographs will be selected and measured on the super-wide-angle photographs, and horizontal and vertical coordinates will be computed for these pass points. More than 100 vertical control points will be withheld to evaluate the results.

Research results of semianalytical aerotriangulation obtained during the year with high-altitude photographs supported the theory that the accuracy of photogrammetrically derived horizontal pass points is a function of the number of models in a computational unit rather than the focal length of the aerial camera used. The results obtained with input from both wide-angle and super-wide-angle cameras were similar when the photograph scales were about the same. With scales that provided coverage of a 7½-minute quadrangle in two stereomodels, both wide-angle and super-wide-angle photographs produced root-mean-square errors of less than 15 feet for 15-minute blocks of photographs with one horizontal control point at each of the four corners of a block.

Photogrammetric computations

Two portable Wang 700 calculators with output writers were purchased during fiscal year 1971 for photogrammetric computations. They are equipped with magnetic-tape cassettes as auxiliary storage units so that either programs or data can be stored and later retrieved from the tape cassettes. The calculators have been used for calibration of pantographs, orientation of photographs by resection, and both linear and nonlinear transformations. All these problems involve solutions by the method of least squares, and therefore a routine has been prepared for solving as many as 12 normal equations. A study will be made to determine the feasibility of interfacing the Wang 700 with the Wild A7 stereoplotter.

A practical method of analytical rectification was developed to speed the production of photographic input for revision, mosaicking, and orthophotomapping. The Zeiss SEG-5 rectifier was analyzed, calibrated, and found to be sufficiently accurate and precise to produce photographs of high geometric quality. A FORTRAN computer program was written to compute easel tilts and magnification by a space-resection method, with coordinates of corresponding photographic control points used as input. A least-squares adjustment supplies residuals for the control points at map scale. Three to 20 points per photo may be used in the adjustment. The results show clearly that the analytical method of rectification with a computer program is superior to the traditional empirical method with respect to time and accuracy. Time has been cut by more than one-half, and accuracy has been improved because poor control points can be eliminated by an analysis of the residuals in the analytical solution.

Automatic orthophoto system

The automatic orthophoto system was developed to meet the steady and increasing demand for orthophotomaps and orthophotoproducts. The components of the system are the profiler, the Autoline, and the Orthophotomat. Profile plots derived from the prototype manual profiler were used successfully to operate the Orthophotomat.

Investigations continued into an automatic technique for photographically recording terrain profiles in a model formed by a double-projection plotter. The profiles are formed optically by the intersection of corresponding rays projected from edge-enhanced positive and negative transparencies. Multiple profiles can be obtained simultaneously. Further development is needed to improve the technique so that all profiles are recorded completely across the model.

The prototype Autoline was completed and tested, and the feasibility of the system was proved. This instrument follows profiles automatically by means of two cadmium sulfide photocells mounted side by side to straddle the line. As the Autoline traces the profiles, signals are generated to control the profiling motions of the Orthophotomat. Satisfactory orthonegatives were produced by the Autoline-Orthophotomat combination.

The prototype Orthophotomat was completed and tested with the rest of the automatic orthophoto system. It is a single-projector, differential rectification instrument for off-line, automatic production of orthophotographs. It scans and exposes the photoimagery in a narrow strip along the profile in the y direction and steps over automatically in the x direction to the next strip at the end of each scan. During scanning, z motion is controlled by electrical signals from the Autoline. The instrument consists of the main support structure, film platen, scanning assembly, and the projector assembly. The light-source assembly is mechanically independent of the projector. Interchangeable exposing slots of different widths are available for different terrain conditions.

CARTOGRAPHY

Instrumentation

The U.S. Geological Survey investigated several instruments for use in developing automatic cartography techniques for both the Earth Resources Observation Systems program and the topographic mapping program. One such instrument, designed by the Geological Survey and now being built by a commercial firm, is a scanner for converting graphic information to digital form. The scanner contains a high-resolution vidicon camera and an optical scanning head which operates under precise geometric and electronic control. It will scan any binary graphic (for example, black and white) and record on magnetic tape the x-y raster address of detected data. Considerable software support is needed for the scanner, and the basic computer programs have been completed. The data produced by the scanner will be input to a data base from which users will be able to derive elevations, slopes, and other terrain information for analyzing remote-sensor imagery. The data can also be retrieved and used to generate other cartographic material with an automatic coordinate plotter.

Another instrument acquired for use in developing cartographic techniques is the Datagrid Digitizer, a product of the Bendix Corp. The instrument will accommodate maps or projected photographic imagery in formats up to 36X48 inches. It is designed to digitize either points or lines in time, point, or distance modes. Block addresses or reference coordinates of data points can be preset into the electronics or typed in via the keyboard. The outputs are digitized line or point data on either computer-compatible magnetic tape or punched paper tape. Software programs of scaling, rotation, and projection fitting are used to modify the magnetic-tape data as may be required for various applications. The instrument is expected to be used in checking existing maps for determining revision requirements, in transferring data from one cartographic medium to another, and in generating digital data for correcting and updating cartographic copy stored in digital form.

The Cartoplot, an in-house development of the Geological Survey, consists principally of a Haag-Streit coordinatograph interfaced with a continuous-path-contouring control unit. The plotter accepts either punched paper-tape data records from the Datagrid Digitizer or a wide variety of prepunched paper-tape programs, and it automatically plots points, vectors, contours, or second-degree curvilinear graphics with a high degree of precision.

Experimental photomechanical techniques

Experiments were conducted in photomechanical techniques of hill shading, slope mapping, and digitizing map detail. In conjunction with the experiments, a revolving illuminator was designed and built to manipulate the line widths of map symbols. The device in arrangement with a printing frame is used to attain line-weight increases and decreases up to 0.2 inch from negative and positive film copies of map drawings.

Two experimental slope maps were produced semiautomatically from contour-plate negatives by increasing the line widths of contours by preselected amounts with the revolving illuminator. The negative copy was manually and photomechanically preprocessed to remove all disruptive symbols, such as contour numbers and spot elevations, and to bring all contour lines to uniform width. From the modified negative contour copy, the revolving illuminator was used to photomechanically generate separate slope zones. The first map portrays five slope zones, each in a distinctive color. For the second map, the area was divided into six zones, with more emphasis given to the flatter areas. The color scheme is made up of three primary colors combined to form progressively darker hues for the steeper areas.

Photomechanical techniques were also used for relief shading. In the first step, the direction of illumination is chosen on a negative plate of contour lines, and a mask is constructed to separate illuminated slopes from shaded slopes. A negative image of the contour lines is then processed to thicken the contours in the direction of illumination. Next, a composite of the mask, the enhanced contours, and a 40-percent screen is made, and this product conveys a three-dimensional illusion. The composite is then used as copy for further photographic processing into a more conventional shaded-relief form that resembles a hand rendering by airbrush. In this process, the recording film is separated from the copy by a translucent diffuser and a 0.1-inch transparent spacer. This technique effectively blends the varying tones on the illuminated and shaded slopes with the screened background. The resultant shadings can be reproduced in halftone and overprinted on a topographic map.

In preparing map copy for digitizing with a scanner, symbols must be separated in categories to reduce manual editing and coding of the digitized information. A photomechanical process that separates symbols on a culture plate by line-width discrimination was used with success to reduce the editorial work involved. In this process, the revolving illuminator is used to selectively and predictably control the spreading and reducing of line widths on lithographic films. These films and the original plate are combined in intermediate masking steps to produce plates with different categories of symbols. The series of resultant abridged plates serve as input for digitizing.

Storage and retrieval of geographic names

Use of the automatic data-processing system of storing geographic names and associated information continued. Printer's copy for "Decision Lists of the Board on Geographic Names" is now being prepared by computer-driven automatic typesetter. Compilation of the geographic names in the Commonwealth of Massachusetts is complete, and most of the names have been prepared for computer storage. Compilation and storage of Rhode Island names will be completed in 1971. The long-range goal is to store the more than 3½ million geographic names in the United States. The standard format used will permit the search and research of name information for use in many disciplines, for example, cartography, geology, water resources, geography, linguistics, and history.

Orthophotomapping

Orthophotomaps, which combine photoimagery with varying amounts of cartographic enhancement, continued to be favorably received by the map-using community. These maps are usually tailored to the particular area and to the expected use for maximum information and utility. Many areas in the United States were reviewed to determine the advantages of protraying them on orthophotomaps.

A group of twelve 1:24,000-scale orthophotomaps has been published for the area of oil discovery around Prudhoe Bay, Alaska. In this project, orthophotographs produced from map-centered, high-altitude photographs were cartographically enhanced and processed, and seven color-separation negatives required for printing were made. Reproduction was done in a commercial plant, which marked the first time Geological Survey orthophotomaps were printed by a private contractor. The elapsed time from aerial photography to publication was less than 7 months.

In an experimental orthophotomapping project, color-separation materials for the Ray NW, Minnesota, quadrangle were prepared, and several colored renditions of the photomap were produced for distribution to State officials for their review and comments. Reaction to the experimental map was favorable, and orthophotomapping of all remaining unmapped areas in the State was requested.

With present orthophotomapping procedures, a considerable amount of manual work is required to delineate features, such as water and vegetation, that appear on separate plates for printing in appropriate colors. A study was started to develop a procedure for printing color photomaps from color or color-infrared aerial photographs, which would reduce or totally eliminate the need to manually produce color-separation plates for color printing of the various categories of map features. A 1:60,000-scale color photograph taken by the

National Aeronautics and Space Administration over the Phoenix, Ariz., area was used as input for an experimental color photomap. The photograph was optically processed through a color-corrected rectifier to simultaneously rectify and color-separate the cyan, magenta, yellow, and black imagery into four black-and-white negatives. The four negatives will be used to prepare color-separation plates for lithographic printing. The colors on the orthophotomap will not necessarily be the same as the colors on the original photograph since variations in shades of the basic ink colors can be selected for the pressplates. Selected planimetric features and names will be overprinted on the orthophotomap.

Other tests were conducted to establish additional controls for processing image-tone materials and to evaluate their potential printing qualities. The results of the tests will help to provide the proper density and contrast ranges in map-reproduction materials. Printing tests were also conducted to develop a system with controls and standards for printing orthophotomap products with a four-color process (yellow, blue, red, and black). The system will provide color standards for all types of terrain classifications and line symbols.

Note.—See also the section "Applications to Cartographic Studies," under "Remote Sensing and Advanced Techniques," p. A202–A205.

COMPUTER TECHNOLOGY

During fiscal year 1971, the U.S. Geological Survey again expanded the availability of facilities of the Computer Center.

New computer terminals were installed at Water Resources Division offices at Salt Lake City, Utah; Atlanta, Ga.; Albany, N.Y.; Trenton, N.J.; and Arlington, Va. These new data terminals permit the teleprocessing of complex computer programs to the large-scale computer at the Washington, D.C., headquarters. Several additional installations are being considered. Along with the data terminals at field locations, the Computer Center has undertaken in-depth research into terminals for interactive computing, using CRT (cathode ray tube) and typewriter style terminals. Investigation of timesharing systems using these media has progressed to the point where a modification of the Houston Automatic Spooling Program (HASP) has been developed and is presently under test. This modification to the HASP control program permits remote job entry via low-speed terminals.

Organization

During the year the Computer Center completed a reorganization which recognized and answered the need to streamline operations via the merger of similar functions and the sequestering of dissimilar functions. This reorganization has as its objectives greater responsiveness to user needs and heightened efficiency. Both of these objectives appear to be well on the way toward being met. Also, a new post of DIPS project leader was established to coordinate the design, development, and execution of the new Departmental Integrated Payroll and Personnel System.

User technical support

Continuing the program of improving technical support for the user, the Computer Center was active on three fronts. First, the Center published Chapter 8 of the "Computer Center Division Users Manual," which defines the purpose and use of the Program Archives Documentation System (PADS) and the Program Archives Source System (PASS). The PADS system gives a ready source of documents on programs maintained by the Computer Center. PASS is a convenient system for both storage and retrieval of source decks and (or) listings of programs maintained by the Computer Center.

Also, to expedite dissemination of critical information to users, a technical tips message has been added to the IBM 360/65 system. When users seek access to the system, in addition to their expected output a special 5-line 80-column message is transmitted to their terminal. These messages are carried on the system for 5 days to assure user awareness. Another area of activity has been training. Several Computer Center programers have completed advanced training in PL/I and FORTRAN programing languages and in Job Control language.

New applications

Of the many new applications of computer technology introduced during the fiscal year, five are of special note. First is the use of digital image-processing techniques for cartographic and photometric applications. A set of generalized image-processing programs, called VICAR, from the University of California's Jet Propulsion Laboratory has been the basis for most of the work. Images in digital form from unmanned spacecraft and images digitized by microdensitometers can be scaled, rectified, enhanced, filtered, rotated, converted to various projections, and freed of distortions. Early work with digital spacecraft images shows that future mapping efforts may use image-processing techniques to replace many existing manual cartographic techniques. A computer program has been developed at the Flagstaff, Ariz., office to produce base maps with accentuated features similar to those produced by airbrush techniques. This procedure looks quite promising for the future development of certain types of maps.

A second new application concerns radioactive-waste disposal. At the Menlo Park, Calif., office, a one-dimensional vertical heat-conduction model of the proposed national depository for solid radioactive waste at Lyons, Kans., was programed and used to calculate 1,000-year histories of the depository. The model extended previous calculations made at Oak Ridge, Tenn., by featuring temperature-dependent thermal properties of salt and shale as measured by John Sass from core samples taken at Lyons. The realism of the model was improved by the inclusion of six thin layers of shale within the salt bed. Calculations were performed in cooperation with W. H. Diment (University of Rochester) and Robert Schneider (USGS).

Another application project in progress is related to offshore drilling and consists of two major new data files. The Computer Center is in the process of building data files via computer support to assist engineers in the control of Outer Continental Shelf platform inspections and to monitor the Maximum Efficient Rate for oil production.

The primary purpose of the Outer Continental Shelf platform file is to provide information on facilities used in the production of gas and oil on the Outer Continental Shelf. The file contains the location and description of structures, including the number of holes and completions that are associated with each structure. The file will also include the results of inspections made of the site. The principal uses of the file will be to guide the inspection program and to compile statistics on the types of completions on the Outer Continental Shelf by area, block, field, lease, type of structure, depth of water, and type of production.

The Maximum Efficient Rate File is a means of checking lease operator's daily production figures against the approved maximum production rates established for all oil and gas wells and reservoirs in accordance with Outer Continental Shelf Order No. 11 and publishing a periodic listing of the maximum production rates for all approved oil and gas wells and reservoirs. The file includes data for all wells used in the production of hydrocarbons in zone 4 on the Outer Continental Shelf in the Gulf of Mexico. The file will also include basic data such as monthly oil-well-potential reports and quarterly gas-well-deliverability reports, producing intervals, operator, reservoir name, days produced, and volumes produced. The main uses of the file will be to enable the Government to monitor production, to compute statistics on production by lease and by operator, and to identify operators and wells producing over their assigned Maximum Production Rates.

The Computer Center implemented two major data base systems. They are the National Military Command Center Information Processing System (NIPS) and Data Presentation System (DPS), both obtained from the Command Center. NIPS is a general data base manager usable with a variety of files, and DPS is a special output program that produces two-dimensional arrays, statistical reports, graphic output, and geographic plots.

Note.—See entries under "Computer Technology" in Subject Index, p. A401, for specific applications of computer technology.

U.S. GEOLOGICAL SURVEY PUBLICATIONS

PUBLICATIONS PROGRAM

Books and maps

Results of research and investigations by the U.S. Geological Survey are made available to the public through professional papers, bulletins, water-supply papers, circulars, miscellaneous reports, and several map and atlas series, most of which are published by the Geological Survey. Of these reports, books are printed and sold by the U.S. Government Printing Office, and maps are printed and sold by the Survey.

All books, maps other than topographic quadrangle maps, and related Geological Survey publications are listed in the catalog "Publications of the Geological Survey, 1879–1961" and in yearly supplements, available on request, that keep the catalog up to date. A combined list of Survey publications issued from 1962 through 1970 will be available in 1972.

New publications, including topographic quadrangle maps, are announced monthly in "New Publications of the Geological Survey." A free subscription to this list may be obtained on application to the U.S. Geological Survey, Washington, D.C. 20242.

State lists of publications on hydrology and geology

"Geologic and Water-Supply Reports and Maps, [State]," a series of booklets, provides a ready reference to these publications on a State basis. The booklets also list libraries in the subject State where Geological Survey reports and maps may be consulted; these booklets are available free on request to the Geological Survey.

The National Atlas

"The National Atlas of the United States of America" was completed and published in fiscal year 1971; 5,690 copies were distributed during the year. Copies of the atlas may be ordered for $100 each (prepayment required) from the Washington Distribution Section, U.S. Geological Survey, 1200 S. Eads St., Arlington, Va. 22202. A 25-percent discount applies to single orders for 25 or more copies.

Surface-water and quality-of-water records

Beginning with the 1961 water year, surface-water records have been released on a State-boundary basis in separate annual reports entitled "Water Resources Data for [State]: Part 1, Surface Water Records." The records will also be published in the Geological Survey series of water-supply papers at 5-year intervals. The first group of "Surface Water Supply" papers covers the water years 1961–65.

Publication of quality-of-water records began in the annual State series in 1964 as "Water Resources Data for [State]: Part 2, Water Quality Records." The annual publication in the Geological Survey water-supply papers of "Quality of Surface Water of the United States" by drainage basins has been continued. Distribution of the State water-resources data, Parts 1 and 2, is limited and primarily for local needs. These reports are free on request to Water Resources Division district offices (listed on p. A252–A253) in areas for which records are needed.

Indexes, by drainage basins, of surface-water records to September 30, 1967, are published in the Geological Survey series of circulars, issues of which are free on application to the U.S. Geological Survey, Washington, D.C. 20242. These indexes list all streamflow and reservoir stations for which records have been published in Geological Survey reports.

"National Reference List of Water Quality Stations, Water Year 1971," lists all the stations at which water-quality data were collected for the 1971 water year. This inventory may also be obtained free from the Survey.

State water-resources investigations folders

A series of 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 (U.S.), 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, or to the Water Resources Division district offices listed on pages A252–A253.

Open-file reports

Open-file reports, which consist of manuscript reports, maps, and other preliminary material, are 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. Most open-file reports are placed in one or more of the three Geological Survey libraries: 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 A249–A253, and interested State agencies. Many open-file reports are superseded later by formally printed publications.

PUBLICATIONS ISSUED

During fiscal year 1971, the Geological Survey published 4,500 maps, comprising some 19,107,400 copies, and 204 technical book reports.

Kind of map	1971
National Atlas pages	218
Topographic	3,637
Geologic and hydrologic	263
Maps for inclusion in book reports	80
Miscellaneous (includes maps for other agencies)	302
Total	4,500

In addition, 994 leaflets and maps of flood-prone areas were published.

At the beginning of the fiscal year, more than 80 million copies of maps and book reports were on hand in the Geological Survey's distribution centers. During the year 8,088,100 copies of maps, including 646,900 index maps, were distributed. Approximately 5.6 million maps were sold, and $1,996,671.08 was deposited to Miscellaneous Receipts in the U.S. Treasury.

The Survey also distributed 473,200 copies of technical book reports, without charge and for official use, and 2,218,000 copies of booklets, free of charge, chiefly to the general public; 180,600 copies of the monthly publications announcements and 230,000 copies of a sheet showing topographic map symbols were sent out.

The total distribution resulted from receipt of 480,300 individual orders. The following table compares Survey map and book distribution (including booklets but excluding symbol sheets and monthly announcements) during fiscal years 1970 and 1971:

Distribution points	Fiscal year 1970	Fiscal year 1971	Change (percent)
Eastern (Arlington, Va.)	5,608,767	5,918,043	+6
Western (Denver, Colo.)	4,415,967	4,761,779	+8
Alaska (Fairbanks)	88,306	80,887	-8
Total	[1]10,113,040	[2]10,760,709	+6

[1]Includes 794,477 items distributed by 12 other Geological Survey offices.

[2]Includes 801,046 items distributed by 12 other Geological Survey offices.

HOW TO OBTAIN PUBLICATIONS

OVER THE COUNTER

Book reports

Book reports currently in print (professional papers, bulletins, water-supply papers, "Topographic Instructions," "Techniques of Water Resources Investigations," and some miscellaneous reports) can be purchased from the Superintendent of Documents, Government Printing Office, Washington, D.C., and from the Geological Survey Public Inquiries Offices listed on page A249.

Maps and charts

Maps and charts may be purchased at the following U.S. Geological Survey offices:

1200 S. Eads St., Arlington, Va.
1028 General Services Bldg., 19th and F Sts., N.W., Washington, D.C.
1109 N. Highland St., Arlington, Va.
900 Pine St., Rolla, Mo.
Building 41, Federal Center, Denver, Colo.
345 Middlefield Rd., Menlo Park, Calif.
441 Federal Building, 710 W. 9th St., Juneau, Alaska
310 1st Ave., Fairbanks, Alaska
Public Inquiries Offices listed on page A249.

Geological Survey maps are also sold by 758 authorized commercial dealers throughout the United States. Prices charged are generally higher than those charged by Geological Survey offices.

Indexes showing topographic maps published for each State, Puerto Rico, the Virgin Islands (U.S.), Guam, and American Samoa are available free on request. Publication of revised indexes to topographic mapping is announced monthly in "New Publications of the Geological Survey." Each index also lists special and United States maps, as well as Geological Survey offices from which maps may be purchased and local dealers who sell the Survey's maps.

BY MAIL

Book reports

Technical book reports, certain leaflets in bulk quantity, and some miscellaneous reports can be ordered from the Superintendent of Documents, Government Printing Office, Washington, D.C. 20402. Prepayment is required and should be made by check or money order payable to the Superintendent of Documents. Postage stamps are not accepted; cash is sent at the sender's risk. On orders of 100 copies or more of the same reports, a 25-percent discount is allowed. Circulars and some miscellaneous reports may be obtained free from the U.S. Geological Survey, Washington, D.C. 20242.

Maps and charts

Maps and charts, including folios and hydrologic atlases, are sold by the Geological Survey. Address orders to Distribution Section, U.S. Geological Survey, 1200 S. Eads St., Arlington, Va. 22202, for maps of areas east of the Mississippi River, including Puerto Rico and the Virgin Islands (U.S.), and to Distribution Section, U.S. Geological Survey, Federal Center, Denver, Colo. 80225, for maps of areas west of the Mississippi, including Alaska, Hawaii, Louisiana, Minnesota, Guam, and American Samoa. An order for both eastern and western maps should be sent to the closer of the two distribution sections listed above. Residents of Alaska may order Alaska maps from Distribution Section, U.S. Geological Survey, 310 1st Ave., Fairbanks, Alaska 99701.

Prepayment is required. Remittances should be by check or money order payable to the U.S. Geological Survey. Prices are quoted in lists of publications and, for topographic maps, in indexes to topographic mapping for individual States. Prices include the cost of surface transportation.

Advance material available from current topographic mapping is indicated on index maps prepared for each State and issued quarterly. This material, which includes such items as aerial photography, geodetic control data, and maps in various stages of preparation and editing, is available for purchase. Information concerning the ordering of these items is contained in the text of the indexes. Requests for the indexes or inquiries concerning the availability of advance material should be directed to the Map Information Office, U.S. Geological Survey, Washington, D.C. 20242.

National Technical Information Service

Some Geological Survey reports, primarily computer programs, data and information supplemental to map or book publications, and data files, are released through the National Technical Information Service. These reports, either in paper copy at $3.00 each for documents of 300 pages or less or in microfiche for 95 cents each, can be purchased *only* from National Technical Information Service, U.S. Department of Commerce, Springfield, Va. 22151. NTIS numbers should be shown on all orders for NTIS documents; Geological Survey reports that are released through NTIS, together with their NTIS numbers, are announced in the monthly "New Publications of the Geological Survey."

PUBLICATIONS OUT OF PRINT

Book publications listed as out of print can no longer be obtained from the Superintendent of Documents, Washington, D.C. However, some books listed as out of print are available for purchase from his authorized agents: U.S. Geological Survey offices at 1012 Federal Building, 1961 Stout St., Denver, Colo. 80202; 8102 Federal Office Building, 125 S. State St., Salt Lake City, Utah 84111; Room 1C45, 1100 Commerce St., Dallas, Tex. 75202; 7638 Federal Building, 300 N. Los Angeles St., Los Angeles, Calif. 90012; 504 Custom House, 555 Battery St., San Francisco, Calif. 94111; 678 U.S. Court House Building, West 920 Riverside Ave., Spokane, Wash. 99201; and 108 Skyline Building, 508 2d Ave., Anchorage, Alaska 99501.

Maps, charts, folios, and atlases that are out of print can no longer be obtained from any official source. These may be consulted at many libraries, and some can be purchased from secondhand-book dealers.

COOPERATORS AND OTHER FINANCIAL CONTRIBUTORS DURING FISCAL YEAR 1971

[Cooperators listed are those with whom the U.S. Geological Survey had a written agreement for fiscal cooperation in fiscal year 1971, cosigned by the Director of the Geological Survey and a responsible official of the cooperating agency. Agencies with whom the Geological Survey had research contracts and to whom it supplied funds for such research are not listed. Parent agencies are listed separately from their subdivisions where separate cooperative agreements for different projects were made with the parent agency and with a subdivision of the parent agency.]

FEDERAL COOPERATORS

Agency for International Development

Atomic Energy Commission:
- Division of Peaceful Nuclear Explosives
- Division of Reactor Development and Technology
- Idaho Operations Office
- Knolls Atomic Power Laboratory
- Los Alamos Scientific Laboratory
- Nevada Operations Office
- Richland Operations Office
- Savannah River Operations Office

Department of Agriculture:
- Agriculture Research Service
- Forest Service
- Soil Conservation Service

Department of the Air Force:
- Alaskan Air Command
- Cambridge Research Laboratory
- North Air Force Base
- Special Weapons Center
- Warner Robins Air Force Base

Department of the Army:
- Army Research Office
- Corps of Engineers
- Environmental Hygiene Agency
- Fort Wingate Army Depot
- Pueblo Army Depot
- Rocky Mountain Arsenal

Department of Commerce:
- National Marine Fisheries Service
- National Oceanic Survey
- National Weather Service

Department of Defense:
- Advanced Research Projects Agency
- Defense Atomic Support Agency

Department of Health, Education, and Welfare, Public Health Service

Department of Housing and Urban Development

Department of the Interior:
- Alaska Power Administration
- Bonneville Power Administration
- Bureau of Indian Affairs
- Bureau of Land Management
- Bureau of Mines

Department of the Interior—Continued
- Bureau of Reclamation
- Fish and Wildlife Service
- National Park Service
- Office of Water Resources Research

Department of Justice, Land and Natural Resource Division

Department of the Navy:
- Key West Naval Station
- Marine Corps Supply Center
- Naval Oceanographic Office
- Naval Weapons Center
- Office of Naval Petroleum and Oil Shale Reserves
- Office of Naval Research

Department of State:
- Agency for International Development
- International Boundary and Water Commission
- International Joint Commission

Environmental Protection Agency, Water Quality Office

Federal Power Commission

National Aeronautics and Space Administration

National Science Foundation

Office of Emergency Preparedness

Tennessee Valley Authority

Water Resources Council

STATE, COUNTY, AND LOCAL COOPERATORS

Alabama:
- Alabama Highway Department
- City of Mobile
- Geological Survey of Alabama

Alaska:
- Alaska Department of Health and Welfare
- Alaska Department of Highways
- Alaska Department of Natural Resources
- Alaska Department of Public Works
- City of Anchorage
- City of Petersburg
- City of Soldatna
- Greater Anchorage Area Borough
- Greater Juneau Borough
- Kenai Peninsula Borough

Arizona:
- Apache County Superior Court
- 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 Tucson
- City of Williams
- Flood Control District of Maricopa County
- Gila Valley Irrigation District
- Maricopa County Municipal Water Conservation District No. 1
- Navajo Tribal Council
- Navajo Tribal Utility Authority
- Pima County Board of Supervisors
- Salt River Valley Water Users' Association
- San Carlos Irrigation and Drainage District
- Show Low Irrigation Company
- University of Arizona

Arkansas:
- Arkansas Geological Commission
- Arkansas State Highway Commission

California:
- Alameda County Flood Control and Water Conservation District
- Alameda County Water District
- Antelope Valley–East Kern Water Agency
- Berrenda Mesa Water District
- California Department of Conservation, Division of Mines and Geology
- California Department of Fish and Game
- California Department of Navigation and Ocean Development
- California Department of Water Resources
- California Reclamation Board
- California Water Resources Control Board
- City of San Diego
- City of Santa Barbara
- City of Santa Cruz
- Coachella Valley County Water District
- Contra Costa County Flood Control and Water Conservation District
- County of Del Norte
- County of Sacramento
- County of San Diego
- County of San Mateo
- County of Tulare
- Desert Water Agency
- East Bay Municipal Utility District
- Georgetown Divide Public Utility District
- Goleta County Water District
- Imperial Irrigation District
- Indian Wells Valley County Water District
- Irvine Ranch Water District
- Joint Administration Committee of the Santa Margarita and San Luis Rey Watershed Planning Agencies
- Lake County Flood Control and Water Conservation District
- Los Angeles County, Department of County Engineers
- Madera County Flood Control and Water Conservation Agency
- Madera Irrigation District
- Metropolitan Water District of Southern California
- Mojave Water Agency
- Montecito County Water District
- Monterey County Flood Control and Water Conservation District
- Napa County Flood Control and Water Conservation District
- Newhall County Water District
- Ojai Soil Conservation District

California–Continued
- Orange County Flood Control District
- Orange County Water District
- Paradise Irrigation District
- Riverside County Flood Control and Water Conservation District
- San Benito County Water Conservation and Flood Control District
- San Bernardino County Flood Control District
- San Bernardino Valley Municipal Water District
- San Francisco City and County Public Utilities Commission
- San Francisco Water Department
- San Luis Obispo County Flood Control and Water Conservation District
- Santa Barbara County Flood Control 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
- Santa Ynez River Water Conservation District
- Siskiyou County Flood Control and Water Conservation District
- Solana Irrigation District
- Sonoma County Water Agency
- Tehachapi–Cummings County Water District
- Terra Bella Irrigation District
- Turlock Irrigation District
- United Water Conservation District
- University of California
- Ventura County Flood Control District
- Ventura River Municipal Water District
- Western Municipal Water District
- Woodbridge Irrigation District
- Yolo County Flood Control and Water Conservation District

Colorado:
- Arkansas River Compact Administration
- City of Aspen
- City of Aurora, Department of Public Utilities
- City of Colorado Springs, Department of Public Utilities
- City and County of Denver, Board of Water Commissioners
- Colorado Division of Water Resources
- Colorado River Water Conservation District
- Colorado State Mining Industrial Development Board
- Colorado Water Conservation Board
- Denver Regional Council of Governments
- Plains Ground-Water Management District
- Southeastern Colorado Water Conservancy District
- State Department of Highways, Division of Highways
- Urban Drainage and Flood Control 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 Water Resources Commission
- Department of Agriculture and Natural Resources
- Department of Transportation
- Greater Hartford Flood Commission
- Southeastern Connecticut Water Authority

Delaware:
- Delaware Geological Survey, University of Delaware
- Delaware Highway Department

District of Columbia:
- Department of Sanitary Engineering

Florida:
- Broward County
- Broward County Pollution Control Authority
- Central and Southern Florida Flood Control District
- City of Boca Raton

Florida—Continued
- City of Fort Lauderdale
- City of Hallandale
- City of Miami, Department of Water and Sewers
- City of Miami Beach
- City of Perry
- City of Pompano Beach
- City of St. Petersburg
- City of Tallahassee
- Collier County
- Collier County Water District No. 1
- Collier County Water District No. 7
- Dade County
- Dade County Port Authority
- East Central Florida Regional Planning Council
- Florida Air and Water Pollution Control Department
- Florida Department of Natural Resources
- Florida Department of Transportation
- Florida Division of Parks and Recreation
- Florida Game and Fresh Water Fish Commission
- Hillsborough County
- Orange County
- Palm Beach County
- Pinellas County
- Polk County
- Seminole County
- Suwanee River Authority
- Tampa Port Authority
- Trustees of the Internal Improvement Trust Fund

Georgia:
- City of Brunswick
- Division of Conservation, Department of Mines, Mining, and Geology
- Georgia Water Quality Control Board
- State Highway Department

Hawaii:
- City and County of Honolulu
- Department of Transportation, Division of Highways
- Honolulu Board of Water Supply
- State Department of Land and Natural Resources, Division of Water and Land Development

Idaho:
- Blaine County Commission
- City of Kellogg
- Idaho Department of Highways
- Idaho Department of Water Administration

Illinois:
- City of Springfield
- County of Cook, Forest Preserve District
- Fountain Head Drainage District
- Northeastern Illinois Planning Commission
- Sanitary District of Bloom Township
- State Department of Public Works and Buildings:
  - Division of Highways
  - Division of Waterways
- State Department of Registration and Education:
  - Illinois State Geological Survey
  - Water Survey Division
- The Metropolitan Sanitary District of Greater Chicago

Indiana:
- Indiana Board of Health
- Indiana Department of Natural Resources
- Indiana Highway Commission

Iowa:
- City of Cedar Rapids

Iowa—Continued
- City of Fort Dodge
- Iowa Geological Survey
- Iowa Natural Resources Council
- Iowa State Conservation Commission
- Iowa State Highway Commission, Highway Research Board
- Iowa State University
- Iowa State University, Agricultural and Home Economics Experiment Station
- Linn County
- University of Iowa, Institute of Hydraulic Research

Kansas:
- City of Wichita
- Kansas State Department of Health
- Kansas State Water Resources Board
- Kansas-Oklahoma Arkansas River Commission
- State Geological Survey of Kansas
- State Highway Commission of Kansas

Kentucky:
- Kentucky Geological Survey, University of Kentucky

Louisiana:
- Louisiana Department of Highways
- Louisiana Department of Public Works
- Sabine River Authority, State of Louisiana

Maine:
- Maine Public Utilities Commission
- Maine State Highway Commission

Maryland:
- City of Baltimore, Water Division
- Maryland Department of Health, Division of Water and Sewage
- Maryland Geological Survey
- Maryland National Capital Park and Planning Commission
- Maryland State Roads Commission
- Montgomery County
- Washington Suburban Sanitary Commission

Massachusetts:
- Massachusetts Department of Public Works:
  - Division of Highways
  - Division of Waterways
- Massachusetts Metropolitan District Commission
- Massachusetts Water Resources Commission:
  - Division of Water Pollution Control
  - Division of Water Resources

Michigan:
- Michigan Department of Natural Resources, Geological Survey Division
- Michigan Water Resources Commission, Department of Conservation

Minnesota:
- Metropolitan Council of the Twin Cities Area
- Minnesota Department of Administration, Minnesota Geological Survey
- Minnesota Department of Conservation, Division of Waters, Soils, and Minerals
- Minnesota Department of Highways
- Minnesota Iron Range Resources and Rehabilitation Commission

Mississippi:
- City of Jackson
- Harrison County Board of Supervisors
- Harrison County Development Commission
- Jackson County Board of Supervisors
- Jackson County Port Authority
- Mississippi Air and Water Pollution Control Commission

Mississippi—Continued
- Mississippi Board of Water Commissioners
- Mississippi Geological Survey
- Mississippi Research and Development Center
- Mississippi State Highway Department
- Pat Harrison Waterway District
- Pearl River Basin Development District
- Pearl River Valley Water Supply District

Missouri:
- Curators of the University of Missouri
- Metropolitan St. Louis Sewer District
- Missouri Department of Business and Administration, Division of Geological Survey and Water Resources
- Missouri State Highway Commission
- Missouri Water Pollution Board
- St. Louis County

Montana:
- Endowment and Research Foundation—Montana State University
- Montana Bureau of Mines and Geology
- Montana State Fish and Game Commission
- Montana State Highway Commission
- Montana Water Resources Board

Nebraska:
- City of Grand Island
- Clay County Ground Water Conservation District
- Hamilton County Ground Water Conservation District
- Nebraska Department of Water Resources
- Nebraska Game and Parks Commission
- Salt Valley Watershed District
- Seward County Ground Water Conservation District
- State Department of Roads
- University of Nebraska, Conservation and Survey Division
- York County Ground Water Conservation District

Nevada:
- Nevada Bureau of Mines
- Nevada Department of Conservation and Natural Resources
- Nevada State Highway Department

New Hampshire:
- New Hampshire Department of Resources and Economic Development
- New Hampshire Water Resources Board

New Jersey:
- County of Bergen
- Delaware River Basin Commission
- New Jersey Department of Agriculture, State Soil Conservation Committee
- New Jersey Department of Environmental Protection:
  - Division of Environmental Quality
  - Division of Fish and Game
  - Division of Water Policy and Supply
- New Jersey Department of Transportation
- North Jersey District Water Supply Commission
- Passaic Valley Water Commission
- Water Resources Research Institute

New Mexico:
- Albuquerque Metropolitan Arroyc Flood Control Authority
- City of Gallup
- Costilla Creek Compact Commission
- Interstate Stream Commission
- New Mexico Bureau of Mines and Mineral Resources
- 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
- Central New York State Parks Commission
- City of Albany
- City of Auburn, Water Department
- County of Dutchess, Water Conservation Division
- County of Nassau, Department of Public Works
- County of Onondaga:
  - Department of Public Works
  - Water Authority
- County of Suffolk:
  - Department of Health
  - Water Authority
- County of Ulster
- County of Westchester, Department of Public Works
- Department of Environmental Conservation
- Department of Transportation
- New York City Board of Water Supply
- New York City Department of Water Resources
- Oswegatchie-Cranberry Reservoir Commission
- Power Authority, State of New York
- Town of Brighton
- Village of Nyack

North Carolina:
- City of Asheville, Public Works Department
- City of Burlington
- City of Charlotte
- City of Durham, Department of Water Resources
- City of Greensboro
- City of Lenoir
- City of Morganton
- City of Raleigh
- City of Winston-Salem
- North Carolina Department of Conservation and Development, Division of Mineral Resources
- North Carolina Department of Water and Air Resources
- State Highway Commission
- Town of Waynesville
- Wake County

North Dakota:
- North Dakota Geological Survey
- Oliver County, Board of County Commissioners
- State Highway Department
- State Water Commission

Ohio:
- City of Columbus, Department of Public Works
- Miami Conservancy District
- Ohio Department of Health
- Ohio Department of Highways
- Ohio Department of Natural Resources, Division of Water
- Ohio River Valley Water Sanitation Commission
- Three Rivers Watershed District

Oklahoma:
- City of Oklahoma City, Water Department
- Oklahoma Department of Highways
- Oklahoma Geological Survey
- Oklahoma Soil Conservation Board
- Oklahoma Water Resources Board
- State Department of Health, Environmental Health Service

Oregon:
- Burnt River Irrigation District
- City of Astoria
- City of Eugene, Water and Electric Board

Oregon--Continued
- City of McMinnville, Water and Light Department
- City of Portland, Bureau of Water Works
- City of The Dalles
- City of Toledo
- Coos County, Board of Commissioners
- Coos Bay—North Bend Water Board
- Douglas County
- Lane County, Board of County Commissioners
- Oregon State Board of Higher Education
- Oregon State Game Commission
- Oregon State Highway Commission
- State Engineer of Oregon
- Water Resources Department, Office of the State Engineer

Pennsylvania:
- Chester County Commissioners
- Chester County Health Department
- Chester County Water Resources Authority
- City of Bethlehem
- City of Easton
- City of Harrisburg
- City of Philadelphia, Water Department
- Delaware River Master
- Pennsylvania Department of Environmental Resources
- Pennsylvania Department of Health
- Pennsylvania Department of Mines and Mineral Industries
- Pennsylvania Department of Transportation
- Pennsylvania State Planning Board, Topographic and Geologic Survey
- Pennsylvania State University, College of Earth and Mineral Sciences

Rhode Island:
- City of Providence, Department of Public Works
- Department of Natural Resources:
  - Division of Fish and Wildlife
  - Division of Harbors and Rivers
- Department of Public Works, Division of Roads and Bridges
- State Water Resources Board

South Carolina:
- Commissioners of Public Works, Spartanburg Water Works
- State Development Board
- State Highway Department
- State Pollution Control Authority
- State Public Service Authority
- State Water Resources Commission

South Dakota:
- Black Hills Conservancy Subdistrict
- City of Sioux Falls
- East Dakota Conservancy Sub-District
- 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 Oak Ridge
- Metropoitan Government of Nashville and Davidson County
- Murfreesboro Water and Sewer Department
- Tennessee Department of Conservation:
  - Division of Geology
  - Division of Water Resources
- Tennessee Department of Highways
- Tennessee Department of Public Health, Stream Pollution Control
- Tennessee Game and Fish Commission

Texas:
- City of Bryan
- City of Dallas
- City of Fort Worth
- City of Houston
- County of Dallas
- Orange County Commissioners Court
- Sabine River Authority of Texas
- Sabine River Compact Administration
- Texas A&M University
- Texas Highway Department
- Texas Water Development Board

Utah:
- Bear River Commission
- Salt Lake County
- Utah Department of Natural Resources, Division of Water Rights
- Utah Geological and Mineralogical Survey
- Utah State Department of Highways

Vermont:
- State Department of Highways
- State Department of Water Resources, Planning and Development Division
- Vermont Geological Survey

Virginia:
- City of Alexandria
- City of Newport News, Department of Public Utilities
- City of Norfolk:
  - Department of Utilities
  - Division of Water Supply
- City of Roanoke
- City of Staunton
- County of Chesterfield
- County of Fairfax
- Virginia Department of Conservation and Economic Development, Division of Mineral Resources
- Virginia Department of Highways

Washington:
- City of Port Angeles
- City of Seattle, Department of Lighting
- City of Tacoma:
  - Department of Public Utilities
  - Department of Public Works
- Clark County Public Utility District
- Cowlitz County Public Utility District
- Department of Ecology
- Evergreen State College
- Lummi Indian Tribe
- Municipality of Metropolitan Seattle
- Port of Seattle
- Washington State Department of Fisheries
- Washington State Department of Game
- Washington State Department of Highways
- Washington State Department of Natural Resources, Division of Mines and Geology
- Yakima Tribal Council

West Virginia:
- Clarksburg Water Board
- Morgantown Water Commission
- West Virginia Department of Highways
- West Virginia Department of Natural Resources, Division of Water Resources
- West Virginia Geological and Economic Survey

Wisconsin:
- Regents of the University of Wisconsin, Geological and Natural History Survey
- Southeastern Wisconsin Regional Planning Commission
- State Department of Natural Resources
- State Department of Transportation, Division of Highways

Wyoming:
- City of Casper, Board of Public Utilities
- City of Cheyenne, Board of Public Utilities
- State Highway Commission of Wyoming
- Wyoming Department of Economic Planning and Development
- Wyoming Game and Fish Commission
- Wyoming Geological Survey
- Wyoming State Agriculture Commission
- Wyoming State Engineer

OTHER COOPERATORS AND CONTRIBUTORS

Government of American Samoa
Government of Guam
Virgin Islands:
- Caribbean Research Institute
- Department of Public Works

Permittees and licensees of the Federal Power Commission
Puerto Rico:
- Puerto Rico Aqueduct and Sewer Authority
- Puerto Rico Department of Public Works
- Puerto Rico Economic Development Administration, Industrial, Research Department
- Puerto Rico Mining Commission

Trust Territory of the Pacific Islands

U.S. GEOLOGICAL SURVEY OFFICES

MAIN CENTERS

Main Office: General Services Building, 18th and F Streets N.W., Washington, D.C. 20242; 202 343-1100
Rocky Mountain Center: Federal Center, Denver, Colo. 80225; 303 233-3611
Pacific Coast Center: 345 Middlefield Road, Menlo Park, Calif. 94025; 415 325-6761

PUBLIC INQUIRIES OFFICES

Location	*Official in charge and telephone number*	*Address*
Alaska, Anchorage 99501	Margaret I. Erwin (907 277-0577)	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 (303 837-4169)	1012 Federal Bldg., 1961 Stout St.
Texas, Dallas 75202	Mary E. Reid (214 749-3230)	Rm. 1 C 45, 1100 Commerce St.
Utah, Salt Lake City 84111	Maurine Clifford (801 524-5652)	8102 Federal Bldg., 125 S. State St.
Washington, Spokane 99201	Eva M. Raymond (509 456-2524)	678 U.S. Court House, West 920 Riverside Ave.

SELECTED FIELD OFFICES IN THE UNITED STATES AND PUERTO RICO

[Temporary offices are not included, list current as of July 1, 1971. Correspondence to the following offices should be addressed to the Post Office Box, if one is given]

COMPUTER CENTER DIVISION

Location	*Official in charge and telephone number*	*Address*
Arizona, Flagstaff 86001	James E. Crawforth (602 774-8863)	601 E. Cedar Ave.
California, Menlo Park 94025	James L. Mueller (415 325-6761, ext. 660)	345 Middlefield Rd.
Colorado, Denver 80225	Frederick B. Sower (303 233-3611, ext. 2341)	Bldg. 25, Federal Center.
Missouri, Rolla 65401	Glenn A. Ridgeway (314 364-6985)	P.O. Box 41.
South Dakota, Sioux Falls 57198	Gary I. Selner	EROS Data Center

CONSERVATION DIVISION

[The small letter in parentheses following each official's name denotes branch affiliation in the Conservation Division as follows: c—Branch of Mineral Classification, m—Branch of Mining Operations, o—Branch of Oil and Gas Operations, w—Branch of Waterpower Classification]

Location	*Official in charge and telephone number*	*Address*
Alaska, Anchorage 99510	Alexander A. Wanek (c) (907 277-0570) Rodney A. Smith (o) (907 277-0579).	P.O. Box 259; 210–214 Skyline Bldg., 218 E St.
California, Los Angeles 90012	Keith A. Yenne (c) (213 688-2846) Donald W. Solanas (o) (213 688-2846).	7744 Federal Bldg., 300 N. Los Angeles St.
Bakersfield 93301	Donald F. Russell (o) (805 323-7201)	309 Federal Bldg., 800 Truxtun Ave.
Menlo Park 94025	Leo H. Saarela (m) (415 325-2563) Willard C. Gere (c) (415 325-2563).	345 Middlefield Rd.
Sacramento 95825	Kenneth W. Sax (w) (916 481-2219)	W-2231 Federal Bldg., 2800 Cottage Way.
Colorado, Denver 80202	Edward R. Haymaker (o) (303 837-4752) John P. Storrs (m) (303 837-4751), William C. Senkpiel (w) (303 837-4753), Robert G. Dickinson (c) (303 837-4752).	6041, 6029, 6023 and 6025 Federal Bldg., 1961 Stout St.

Location	*Official in charge and telephone number*	*Address*
Colorado—Continued		
Denver 80225	George H. Horn (c) (303 233-8168)	Bldg. 25, Federal Center.
Durango 81302	Jerry W. Long (o) (303 247-5144)	P.O. Box 1809; Jarvis Bldg., 125 W. 10th St.
Louisiana, Lafayette 70501	James O. Hinds (c) George Kinsel (o) (318 232-6037).	P.O. Box 52289; 239 Bendel Rd.
Metairie 70004	Robert F. Evans (o), Gayle A. Oglesby (c) (504 527-2424).	P.O. Box 546; 336 Imperial Office Bldg., 3301 N. Causeway Blvd.
Montana, Billings 59103	Albert F. Czarnowsky (m) Virgil L. Pauli (o) (406 245-6368), Elmer M. Schell (c) (406 245-6367).	P.O. Box 2550; 217 Post Office Bldg.
New Mexico, Artesia 88210	James A. Knauff (o) (505 746-4841)	Drawer U; 304 Carper Bldg., 105 S. 4th St.
Carlsbad 88220	Robert S. Fulton (m) (505 885-6454) Larry Godwin (c) (505 885-9082).	P.O. Box 1716; Federal Bldg., 114 S. Halagueno St.
Farmington 87401	Philip T. McGrath (o), J.E. Fassett (c) (505 325-4572).	P.O. Box 959; 409 Petroleum Club Plaza, 3535 E. 30th St.
Hobbs 88240	Arthur R. Brown (o) (505 393-3612)	Box 1157; 205 N. Linam St.
Roswell 88201	N. O. Frederick (o) (505 622-9857) Donal M. Van Sickle (c) (505 622-9857).	Drawer 1857; Federal Bldg. and U.S. Courthouse, Richardson Ave. at 5th St.
Oklahoma, McAlester 74501	Alexander M. Dinsmore (m) (918 423-5030)	P.O. Box 816; 509 S. 3d St.
Miami 74354	Claro V. Collins (m) (918 542-9481)	P.O. Box 509; 205 Federal Bldg.
Oklahoma City 73102	Charley W. Nease (o) (405 231-4011)	4321 Federal Courthouse and Office Bldg., 220 N.W. 4th St.
Tulsa 74103	Edward L. Johnson (c) (918 584-7638) Jess H. Hengst (o) (918 584-7151).	4562 and 3413 New Federal Bldg., 333 W. 4th St.
Oregon, Portland 97208	Jesse L. Colbert (w) (503 234-4796)	P.O. Box 3202, 830 N.E. Holladay St.
Utah, Salt Lake City 84111	Jackson W. Moffitt (m) (801 524-5646) Gerald R. Daniels (o) (801 524-5650) Howard F. Albee (c) (801 524-5643).	8432, 8416, and 8422 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	Charles J. Curtis (o) (307 265-3405) Willis L. Rohrer (c) (307 265-3421).	P.O. Box 2859 and 3273; 2002 and 2001 Federal Bldg. and Post Office, 100 East B St.
Newcastle 82701	Glenn E. Worden (o) (307 746-2737)	P.O. Box 219; 214 W. Main St., Masonic Temple Bldg.
Rock Springs 82901	John A. Fraher (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.

GEOLOGIC DIVISION

OFFICES

Location	*Official in charge and telephone number*	*Address*
Alaska, Anchorage 99501	Donald H. Richter (907 272-8228)	216 Skyline Bldg., 218 E St.
College 99701	Florence R. Weber (907 479-7245)	P.O. Box 5-580; Brooks Memorial Bldg.
Arizona, Flagstaff 86001	John F. McCauley (602 774-5261, ext. 1455) John D. Strobell (602 774-5261, ext. 1463).	601 E. Cedar Ave.
California, La Jolla 92037	George W. Moore (714 453-2820, ext. 341)	P.O. Box 271; 8604 La Jolla Shores Dr.
Hawaii, Hawaii National Park 96718	Donald W. Peterson (967-7485)	Hawaiian Volcano Observatory.
Kentucky, Lexington 40508	Wilds W. Olive (606 252-2312, ext. 2552)	710 W. High St.
Massachusetts, Boston 02110	Lincoln R. Page (617 223-7202)	80 Broad St.
Woods Hole 02543	Martin F. Kane (617 548-8533)	U.S. Geological Survey, Woods Hole Oceanographic Institution.
New Mexico, Albuquerque 87106	Charles B. Read (505 843-2483)	P.O. Box 4083; Station A, Geology Bldg., Univ. of New Mexico.
Ohio, Columbus 43210	James M. Schopf (614 421-2393)	Orton Hall, Ohio State Univ., 155 S. Oval Dr.
Puerto Rico, San Juan 00936	John M. Aaron (809 766-5340)	GPO Drawer 2230.
Santurce 00910	Dennis P. Cox (809 725-6550, ext. 259)	Department of Public Works, Natural Resources Laboratory, P.O. Box 8218.
Tennessee, Knoxville	Robert A. Laurence (615 524-4011, ext. 4268)	301 W. Cumberland Ave.
Texas, Austin 78701	D. Hoye Eargle (512 475-5959)	801 Federal Center.
Corpus Christi 78411	Louis E. Garrison (512 883-5293)	P.O. Box 6732; Univ. of Corpus Christi.
Utah, Salt Lake City 84111	Lowell S. Hilpert (801 524-5640)	8426 Federal Bldg.
Washington, Spokane 99201	Albert E. Weissenborn (509 456-4677)	West 920 Riverside Ave.

Location	*Official in charge and telephone number*	*Address*
Wisconsin, Madison 53706	Carl E. Dutton (608 262-1234, ext. 1854)	222 Science Hall, Univ. of Wisconsin.
Platteville 53818	Walter S. West (608 348-6486)	Wisconsin State Univ., Rountree Hall.
Wyoming, Laramie 82070	J. David Love (307 745-4495)	Box 3007, Univ. Station, Geology Hall, Univ. of Wyoming.

RESPONSIBLE OFFICERS FOR INDIVIDUAL STATES

[Inquiries about Geologic Division programs should be directed to the appropriate officer listed below]

State	*Responsible officer and telephone number*	*Address*
	Northeastern, Atlantic, and Southeastern States	
Connecticut, Massachusetts, and New Hampshire.	Richard Goldsmith (301 474-4800, ext. 567)	Bldg. 420, Agricultural Research Center, Beltsville, Md. 20705.
	Lincoln R. Page (617 223-7202)	80 Broad St., Boston, Mass. 02110.
Alabama, Delaware, Florida, Georgia, Maryland, New Jersey, North Carolina, Pennsylvania, Rhode Island, South Carolina, Virginia, and West Virginia.	Richard Goldsmith (301 474-4800, ext. 567)	Bldg. 420, Agricultural Research Center, Beltsville, Md. 20705.
Maine, New York, Tennessee, and Vermont.	Frank G. Lesure (202 282-7144)	U.S. Geological Survey, Bldg. 10, Washington, D.C. 20242.
	Mississippi Valley	
Arkansas, Illinois, Indiana, Iowa, Kentucky, Louisiana, Mississippi, and Ohio.	W. W. Olive (606 252-2552)	710 W. High St., Lexington, Ky. 40508.
Michigan, Minnesota, Missouri, and Wisconsin.	Frank G. Lesure (202 282-7144)	U.S. Geological Survey, Bldg. 10, Washington, D.C. 20242.
	North-Central, South-Central, and Rocky Mountains	
Colorado, Kansas, Montana, South Dakota, and Texas.	Daniel R. Shawe (303 233-6645)	Bldg. 25, Federal Center, Denver, Colo. 80225.
Idaho, Nebraska, New Mexico, North Dakota, Oklahoma, and Wyoming.	Edward T. Ruppel (303 233-8234)	Do.
Arizona, Nevada, and Utah	E. W. Tooker (415 325-2650)	345 Middlefield Rd., Menlo Park, Calif. 94025.
	Pacific States	
California, Oregon, and Washington	Howard D. Gower (415 325-2353)	345 Middlefield Rd., Menlo Park, Calif. 94025.
Alaska	George Gryc (415 325-2231)	Do.

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	Albert E. Letey (303 233-2351)	Bldg. 25, Federal Center.
Missouri, Rolla 65401	A. Carroll McCutchen (314 364-3680)	P.O. Box 133; 9th and Elm Sts.
Virginia, Arlington 22201	Peter F. Bermel (703 557-0927)	1109 N. Highland St.

WATER RESOURCES DIVISION

REGIONAL OFFICES

Location	*Official in charge and telephone number*	*Address*
Atlantic Coast Region:		
Arlington, Va. 22209	George E. Ferguson, Regional Hydrologist (202 343-8841).	Rm. 317 George Washington Bldg., Arlington Towers, 1011 Arlington Blvd.

Location	*Official in charge and telephone number*	*Address*
Midcontinent Region:		
St. Louis, Mo. 63141	Elwood R. Leeson, Regional Hydrologist (314 268-7224).	Suite 212, 2222 Schuetz Rd.
Rocky Mountain Region:		
Denver, Colo. 80225	Thad G. McLaughlin, Regional Hydrologist (303 233-3611, ext. 6701).	Bldg. 25, Federal Center.
Pacific Coast Region:		
Menlo Park, Calif. 94025	Warren W. Hastings, Regional Hydrologist (415 325-6761, ext. 337, 339, 487).	345 Middlefield Rd.

DISTRICT OFFICES

Location	*Official in charge and telephone number*	*Address*
Alabama, Tuscaloosa 35486	William L. Broadhurst (205 345-8226)	P.O. Box V; Rm. 202, Oil and Gas Board, Univ. of Alabama.
Alaska, Anchorage 99501	Harry Hulsing (907 277-5526, 5527)	Skyline Bldg., 218 E St.
Arizona, Tucson 85717	Horace M. Babcock (602 792-6391, 6395)	P.O. Box 4070.
Arkansas, Little Rock 72201	Richard T. Sniegocki (501 372-5246, 5247)	Rm. 2301, Federal Office Bldg., 700 W. Capitol Ave.
California, Menlo Park 94025	R. Stanley Lord (415 325-6761, ext. 326, 327, 465, 466).	855 Oak Grove Ave.
Colorado, Denver 80225	Edward A. Moulder (303 233-3611, ext. 8621)	Bldg. 25, Federal Center.
Connecticut, Hartford 06101	John A. Baker (203 244-2528)	P.O. Box 715; Rm. 235, Post Office Bldg.
Delaware	Walter F. White, Jr. (301 828-7460)	See Maryland District Office.
District of Columbia	Walter F. White, Jr. (301 828-7460)	See Maryland District Office.
Florida, Tallahassee 32304	Clyde S. Conover (904 224-1202, 1203)	903 W. Tennessee St., Rm 217 Gunter Bldg.
Georgia, Atlanta 30309	John R. George (404 526-3981)	Rm. 301, 900 Peachtree St., N.E.
Hawaii, Honolulu 96814	Willis L. Burnham (546-5692, 5693, 5694, 5695).	Rm. 330 First Insurance Bldg., 1100 Ward Ave.
Idaho, Boise 83702	Hal K. Hall (208 342-2711, ext. 2538)	Rm. 365, Federal Bldg., 550 W. Fort St.
Illinois, Champaign 61820	Davis W. Ellis (217 359-3918)	P.O. Box 1026; 605 N. Neil St.
Indiana, Indianapolis 46202	James L. Cook (317 633-7398)	1819 North Meridian St.
Iowa, Iowa City 52240	Sulo W. Wiitala (319 338-0581, ext. 475, 476).	Suite F, 1041 Arthur St.
Kansas, Lawrence 66044	Charles W. Lane (913 864-4321)	P.O. Box 3267; 19th and Iowa Sts.
Kentucky, Louisville 40202	Robert V. Cushman (502 582-5241, 5242, 5243)	Rm. 572, Federal Bldg., 600 Federal Place.
Louisiana, Baton Route 70806	Albert N. Cameron (504 348-4281)	Rm. 215, Prudential Bldg., 6554 Florida Blvd.
Maine, Augusta 04330	Gordon S. Hayes (207 289-3484)	State House Annex, Capitol Shopping Center.
Maryland, Parkville 21234	Walter F. White, Jr. (301 661-4664)	8809 Satyr Hill Rd.
Massachusetts, Boston 02203	Charles E. Knox (617 223-2822)	Rm. 2300, John F. Kennedy Federal Bldg.
Michigan, Lansing 48933	Timmy R. Cummings (517 372-1910, ext. 561)	Rm. 700, Capitol Savings and Loan Bldg., 112 E. Allegan St.
Minnesota, St. Paul 55101	Charles R. Collier (612 725-7841, 7842)	Rm. 1033 Post Office Bldg.
Mississippi, Jackson 39206	Lamar E. Carroon (601 948-7821, ext. 326)	430 Bounds St.
Missouri, Rolla 65401	Anthony Homyk, Jr. (314 364-1599)	P.O. Box 340; 103 W. 10th St.
Montana, Helena 59601	George M. Pike (406 442-9040, ext. 3263)	P.O. Box 1696, Rm. 421, Federal Bldg.
Nebraska, Lincoln 68508	Kenneth A. MacKichan (402 475-3643)	Rm. 127, Nebraska Hall, 901 N. 17th St.
Nevada, Carson City 89701	George F. Worts, Jr. (702 882-1388)	Rm. 229, Federal Bldg. 705 N. Plaza St.
New Hampshire	Charles E. Knox (617 223-2822)	See Massachusetts District Office.
New Jersey, Trenton 08607	John E. McCall (609 599-3511, ext. 212, 213)	P.O. Box 1238; Rm. 420, Federal Bldg. 402 East State St.
New Mexico, Albuquerque 87106	William E. Hale (505 843-2246)	P.O. Box 4369; Geology Bldg., 2d floor, Univ. of New Mexico Campus.
New York, Albany 12201	Robert J. Dingman (518 472-3107)	P.O. Box 948; Rm. 343, U.S. Post Office and Court House.
North Carolina, Raleigh 27602	Ralph C. Heath (919 755-4510)	P.O. Box 2857; Rm. 440 Century Sta. Post Office Bldg.
North Dakota, Bismarck 58501	Robert C. Williams (701 255-4011, ext. 227, 228).	P.O. Box 778; Rm. 348, New Federal Bldg.
Ohio, Columbus 43212	John J. Molloy (614 469-5553, 5554)	975 W. 3d Ave.
Oklahoma, Oklahoma City 73102	James H. Irwin (405 231-4256, 4257, 4258, 4259).	Room 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; 830 N.E. Holladay St.

Location	*Official in charge and telephone number*	*Address*
Pennsylvania, Harrisburg 17108	Norman H. Beamer (717 782-3468)	P.O. Box 1107; 4th Floor, 228 Walnut St.
Puerto Rico, San Juan 00934	Donald G. Jordan (809 783-4660)	Bldg. 652, Ft. Buchanan.
Rhode Island	Charles E. Knox (617 223-2822)	See Massachusetts District Office.
South Carolina, Columbia 29204	John S. Stallings (803 252-3751, 3752)	2346 Two Notch Rd.
South Dakota, Huron 57350	John E. Powell (605 352-8651, ext. 293, 294)	P.O. Box 1412; Rm. 231, Federal Bldg.
Tennessee, Nashville 37203	Edward J. Kennedy (615 749-5424)	Rm. 144, Federal Bldg.
Texas, Austin 78701	Ivan D. Yost (512 475-5766, 5767, 5768)	630 Federal Bldg., 300 E. 8th Ave.
Utah, Salt Lake City 84111	Theodore Arnow (801 524-5663, 5657, 5658)	Rm. 8002, Federal Bldg., 125 S. State St.
Vermont	Charles E. Knox (617 223-2822)	See Massachusetts District Office.
Virginia, Richmond 23220	James W. Gambrell (703 782-2427, 2428)	200 W. Grace St., Rm. 304.
Washington, Tacoma 98402	Leslie B. Laird (206 383-2861, ext. 384)	Rm. 300, 1305 Tacoma Ave., South.
West Virginia, Charleston 25301	William C. Griffin (304 343-6181, ext. 310, 311).	Rm. 3303, New Federal Bldg. and U.S. Court House, 500 Quarrier St., East.
Wisconsin, Madison 53706	Charles L. R. Holt, Jr. (608 262-2488)	Rm. 200, 1815 University Ave.
Wyoming, Cheyenne 82001	Robert L. Cushman (307 778-2220, ext. 2111)	P.O. Box 2087, 2d Floor, Blue Cross Bldg., 215 E. 8th Ave.

OFFICES IN OTHER COUNTRIES

GEOLOGIC DIVISION

Location	*Official in charge*	*Address*
Brazil, Rio de Janeiro	Max G. White	U.S. Geological Survey, USAID/Rio de Janeiro/ENRG, APO New York 09676.
Belo Horizonte		U.S. Geological Survey, USAID/USGS/Belo Horizonte, APO New York 09676.
Salvador		U.S. Geological Survey, c/o American Consulate, USAID/USGS/Salvador, APO New York 09676.
Colombia, Bogotá	Earl M. Irving	U.S. Geological Survey, AID/UID Bogotá, c/o American Embassy, Bogotá, Colombia.
Indonesia, Bandung	Montis R. Klepper	U.S. Geological Survey, c/o American Embassy, USAID/ENGR, APO San Francisco 96356.
Liberia, Monrovia	Alfred H. Chidester	U.S. Geological Survey, c/o American Embassy, AID/Geology, APO New York 09155.
Saudi Arabia, Jiddah	James J. Norton	U.S. Geological Survey, c/o American Embassy, APO New York 09697.
Dhahran		U.S. Geological Survey, American Consulate General, APO New York 09616.
Turkey, Ankara	Paul W. Richards	U.S. Geological Survey, AID, c/o American Embassy, APO New York 09254.

WATER RESOURCES DIVISION

Location	*Official in charge*	*Address*
Brazil, Rio de Janeiro	Woodrow W. Evett	U.S. AID Rio/ENRN/USGS, APO New York 09676.
Ethiopia, Addis Ababa	Harold E. Gill	U.S. AID, APO New York 09319.
Kenya, Nairobi	W. V. Swarzenski	U.S. AID/Nairobi, U.S. Dept. of State, Washington, D.C. 20521.
Nepal, Katmandu	G. Chase Tibbitts, Jr.	U.S. Geological Survey, U.S. AID/Katmandu, U.S. Dept. of State, Washington, D.C. 20521.
Pakistan, Dacca	James R. Jones	U.S. AID/Dacca (ID) U.S. Dept. of State, Washington, D.C. 20521.
Lahore	Paul R. Seaber	U.S. Geological Survey, U.S. AID/Lahore, U.S. Dept. of State, Washington, D.C. 20521.

INVESTIGATIONS IN PROGRESS IN THE CONSERVATION, GEOLOGIC, AND WATER RESOURCES DIVISIONS

Investigations in progress during fiscal year 1971 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. A249, 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 after the name of the project leader shows the Division technical responsibility: c, Conservation Division; w, Water Resources Division; no letter, Geologic Division.

The projects are classified by principal topic. Most geologic-mapping projects involve special studies of stratigraphy, petrology, geologic structure, or mineral deposits, but are listed only under "Geologic Mapping" unless a special topic or commodity is the primary justification for the project. A reader interested in investigations of volcanology, for example, should look under the heading "Geologic Mapping" for projects in areas of volcanic rocks, as well as under the heading "Volcanology." Likewise, most water-resources investigations involve special studies of several aspects of hydrology and geology, but are listed only under "Water Resources" unless a special topic—such as floods or sedimentation—is the primary justification for the project.

Areal geologic mapping is subdivided into mapping at scales smaller than 1 inch to 1 mile (for example, 1:250,000), and mapping at scales of 1 inch to 1 mile, or larger (for example, 1:62,500; 1:24,000).

Abstracts. *See* Bibliographies and abstracts.

Analytical chemistry:
- Activation analysis (J. Rowe, W)
- Analytical methods—water chemistry (M. W. Skougstad, w, D)
- Analytical services and research (J. I. Dinnin, W; C. Huffman, Jr., D; C. O. Ingamells, M)
- Behavior of organic materials in water (M. C. Goldberg, w, D)
- Instrumentation (J. F. Abell, W)
- Mineral deposits, characteristic analysis (J. M. Botbol, D)
- Natural organic, macromolecules in water (R. L. Wershaw, w, D)
- Organic geochemistry and infrared analysis (I. A. Breger, W)
- Organic substances—pesticides—in water (D. F. Goerlitz, w, M)
- Pesticides, determination in water (C. G. Angelo, w, Columbus, Ohio)
- Puerto Rico laboratory, training and technical aid (A. P. Marranzino, D)
- Radioactivation and radiochemistry (H. T. Millard, D)
- Radiometric methods of analysis (L. L. Thatcher, w, D)
- Recovery, separation, and identification of phenolic compounds from polluted water (S. D. Faust, w, Trenton, N.J.)
- Rock and mineral chemical analysis (J. J. Fahey, W)
- Rock chemical analysis:
  - General (L. C. Peck, D)
  - Rapid (L. Shapiro, W)
- Sample control (H. Bastron, M)
- Services (J. L. Ramisch, W; L. B. Riley, D)
- Spectrochemistry (E. L. Mosier, D)

Analytical chemistry--Continued
- Trace analysis methods, research (F. N. Ward, D)
- Ultratrace analysis (H. T. Millard, D)
- Water analysis, quality control (E. Brown, w, D)
- *See also* Spectroscopy.

Arctic engineering geology (R. Kachadoorian, M)

Artificial recharge:
- Artificial recharge of fractured carbonate rocks (H. O. Reeder, w, St. Paul, Minn.)
- California, artificial recharge, Santa Ana Valley (J. A. Moreland, w, Garden Grove)
- Florida:
  - Artificial recharge study, eastern Orange County (D. D. Knochenmus, w, Ocala)
  - Floridan aquifer, west-central area (W. C. Sinclair, w, Tampa)
  - Injection of wastes in deep wells (D. A. Goolsby, w, Ocala)
  - Subsurface waste storage, Pinellas County (R. N. Cherry, w, Tampa)
  - Subsurface waste storage, statewide (M. I. Kaufman, w, Tallahessee)
- New York:
  - Prediction of movement in zone of aeration, Long Island, (R. C. Prill, w, Mineola)
  - Treated sewage through an injection well, Bay Park, Long Island (J. Vecchioli, w, Mineola)
- Texas, artificial recharge study—High Plains of Texas and New Mexico (R. F. Brown, w, Lubbock)

Asbestos:
- Southeastern United States, ultramafic rocks (D. M. Larrabee, W)

Ferro-alloy metals--Continued
- Tungsten, North Carolina, Hamme district (J. E. Gair, W)
- Ultramafic rocks of the Southeastern United States (D. M. Larrabee, W)
- Idaho, Blackbird Mountain area (J. S. Vhay, Spokane, Wash.)
- Montana, chromite resources and petrology, Stillwater complex (E. D. Jackson, M)
- Oregon, John Day area (T. P. Thayer, W)

Flood characteristics of streams at selected sites:
- Alabama, flood studies and bridge-site investigations (C. O. Ming, w, Tuscaloosa)
- Florida, bridge-site investigations (W. C. Bridges, w, Tallahassee)
- Georgia, Bridge-site investigations (C. M. Bunch, w, Atlanta)
- Iowa, flood information at selected bridge sites (O. G. Lara, w, Iowa City)
- Kansas, characteristics of flood hydrographs (E. R. Hedman, w, Lawrence)
- Mississippi, bridge-site flood investigations (C. H. Tate, w, Jackson)
- Montana, bridge-site investigations (M. V. Johnson, R. J. Omang, w, Helena)
- Nebraska (E. W. Beckman, w, Lincoln)
- New Mexico, peak flood-flow characteristics of small streams (A. G. Scott, w, Santa Fe)
- North Dakota (O. A. Crosby, w, Bismarck)
- Ohio (R. I. Mayo, w, Columbus)
- Oregon, flood profiles, Rogue and Applegate Rivers (D. D. Harris, w, Portland)
- South Carolina (B. H. Whetstone, w, Columbia)
- Tennessee (W. J. Randolph, w, Nashville)
- Utah, cloudburst floods in Utah 1939-70 (E. Butler, w, Salt Lake City)
- West Virginia (P. M. Frye, w, Charleston)
- Wyoming, flood studies and bridge-site investigations (S. A. Druse and D. J. O'Connell, w, Cheyenne)

Flood discharge from small drainage areas:
- Colorado (G. L. Ducret, Jr., w, Denver)
- Connecticut (M. P. Thomas, w, Hartford)
- Delaware (R. H. Simmons, w, Dover)
- Florida (W. C. Bridges, w, Tallahassee)
- Georgia (C. M. Bunch, w, Atlanta)
- Idaho (C. A. Thomas, w, Boise)
- Illinois (J. D. Camp, w, Champaign)
- Iowa (O. G. Lara, w, Iowa City)
- Kansas (T. J. Irza, w, Lawrence)
- Maine (R. A. Morrill, w, Augusta)
- Maryland (D. H. Carpenter, w, College Park)
- Massachusetts (C. G. Johnson, Jr., w, Boston)
- Minnesota (L. C. Guetzkow, w, St. Paul)
- Mississippi (J. W. Hudson, w, Jackson)
- Montana (M. V. Johnson, R. J. Omang, w, Helena)
- Nebraska (E. W. Beckman, w, Lincoln)
- New Jersey (S. J. Stankowski, w, Trenton)
- North Dakota (O. A. Crosby, w, Bismarck)
- Ohio (E. E. Webber, w, Columbus)
- Oregon (J. Friday, w, Portland)
- Rhode Island (C. G. Johnson, Jr., w, Boston, Mass.)
- South Carolina (B. H. Whetstone, w, Columbia)
- South Dakota (L. D. Becker, w, Huron)
- Tennessee, statewide (H. C. Wibben, w, Nashville)
- Texas (E. E. Schroeder, w, Austin)

Flood discharge from small drainage areas--Continued
- Vermont (C. G. Johnson, Jr., w, Boston, Mass.)
- Virginia (E. M. Miller, w, Richmond)

Flood frequency:
- Alabama, flood frequency synthesis for small streams (J. F. McCain, w, Tuscaloosa)
- Colorado, Denver metropolitan area (G. L. Ducret, Jr., w, Denver)
- Georgia (C. M. Bunch, w, Atlanta)
- Illinois (J. D. Camp, w, Champaign)
- Iowa (O. G. Lara, w, Iowa City)
- Kansas (T. J. Irza, P. R. Jordan, w, Lawrence)
- Kentucky, magnitude and frequency (C. H. Hannum, w, Louisville)
- Louisiana:
  - Flood frequency of small areas (A. S. Lowe, w, Baton Rouge)
  - Hydrology and hydraulics for highways (B. L. Neely, w, Baton Rouge)
- New Jersey, magnitude and frequency and effect of basin characteristics (S. J. Stankowski, w, Trenton)
- North Carolina, flood frequency and high-flow studies (N. M. Jackson, w, Raleigh)
- Tennessee, magnitude and frequency of floods on small streams (H. C. Wibben, w, Nashville)
- Utah, magnitude and flood frequency (F. K. Fields, w, Salt Lake City)
- Wisconsin, magnitude and frequency (D. H. Conger, w, Madison)

Flood-inundation mapping:
- Flood-inundation maps (G. Edelen, w, W)
- Alaska, mapping of flood-prone areas (H. Hulsing, w, Anchorage)
- Hawaii (C. J. Ewart, w, Honolulu)
- Illinois:
  - Belleville (J. D. Camp, w, Champaign)
  - Northeastern (A. W. Noehre, w, Oak Park)
- Kentucky (C. H. Hannum, w, Louisville)
- Minnesota, flood-plain mapping (L. C. Guetzkow, w, St. Paul)
- Missouri:
  - Hydrology of streams, St. Louis County (T. W. Alexander, w, St. Louis)
  - Metropolitan St. Louis Sewer District (D. W. Spencer, w, St. Louis)
- New Jersey (S. J. Stankowski and S. L. Laskowski, w, Trenton)
- New York (B. Dunn, w, Albany)
- Pennsylvania, Schuylkill River basin, upstream from Plymouth Dam (W. F. Busch, Harrisburg)
- Puerto Rico (w, San Juan):
  - Caguas, Juncos, Gurabo, San Lorenzo areas (F. K. Fields)
  - Carolina—Río Grande area (W. J. Haire)
  - Culebrinas-Aguada area (W. J. Haire)
  - Fajardo-Luquillo area (W. J. Haire)
  - Guanajibo Valley (W. J. Haire)
  - Jobos-Guayama area (W. J. Haire)
  - Patillas-Maunabo area (W. J. Haire)
  - Salinas area (W. J. Haire)
  - San Sebastian area (W. J. Haire)
  - Santa Isabel area (W. J. Haire)
  - Urban flood inundation, Río Piedras basin (W. J. Haire)
- South Dakota, 75 quadrangles (O. J. Larimer, w, Huron)

Geologic mapping--Continued

- Map scale 1 inch to 1 mile, and larger--Continued
  - California--Continued
    - Hernandez Valley quadrangle (W. C. Gere, c, Los Angeles)
    - Klamath Mountains, southern part (W. P. Irwin, M)
    - Los Angeles basin, eastern part (T. H. McCulloh, M)
    - Malibu Beach quadrangle (R. F. Yerkes, M)
    - Merced Peak quadrangle (D. L. Peck, W)
    - Point Dume and Triunto quadrangles (R. H. Campbell, M)
    - Priest Valley SE quadrangle (W. C. Gere, c, Los Angeles)
    - Sacramento Valley, northwest part (R. D. Brown, Jr., M)
    - Salinas Valley (D. L. Durham, M)
    - Searles Lake area (G. I. Smith, M)
    - Sierra Nevada batholith (P. C. Bateman, M)
    - White Mountain Peak quadrangle (D. F. Crowder, M)
  - Colorado:
    - Aspen 15-minute quadrangle (B. Bryant, D)
    - Black Canyon of the Gunnison River (W. R. Hansen, D)
    - Bonanza quadrangle (R. E. Van Alstine, W)
    - Buckhorn Lakes quadrangle (R. G. Dickinson, c, D)
    - Central City area (R. B. Taylor, D)
    - Cochetopa area (J. C. Olson, D)
    - Courthouse Mountain quadrangle (R. G. Dickinson, c, D)
    - Denver basin, Tertiary coal zone (P. E. Soister, c, D)
    - Denver metropolitan area (R. M. Lindvall, D)
    - Front Range, northeastern part, Fort Collins area (W. A. Braddock, D)
    - Indian Hills Precambrian (B. H. Bryant, D)
    - Jefferson quadrangle (F. Barker, D)
    - Kremmling quadrangle (G. A. Izett, c, D)
    - Montezuma quadrangle (F. Barker, D)
    - Nederland quadrangle (D. J. Gable, D)
    - Niwot quadrangle (D. E. Trimble, D)
    - Northern Park Range (G. L. Snyder, D)
    - Peoria quadrangle (P. E. Soister, c, D)
    - Platoro caldera and related volcanic rocks, southeastern San Juan Mountains (P. W. Lipman, D)
    - Poncha Springs quadrangle (R. E. Van Alstine, W)
    - Rangely 7½-minute and Rangely NE quadrangles (H. L. Cullins, c, Meterie, La)
    - Rico district (E. T. McKnight, W)
    - Ruedie quadrangle (V. L. Freeman, D)
    - San Juan mining area (R. G. Luedke, W)
    - Savery quadrangle (C. S. V. Barclay, c, D)
    - Squaw Pass and Evergreen quadrangles (D. M. Sheridan, D)
    - Straight Creek tunnel (F. T. Lee, D)
    - Strasburg NW and SW quadrangles (P. E. Soister, c, D)
    - Ward and Gold Hill quadrangles (D. J. Gable, D)
    - Washboard Rock quadrangle (R. G. Dickinson, c, D)
    - Watkins and Watkins SE quadrangles (P. E. Soister, c, D)
    - Wet Mountains (Q. D. Singewald, Beltsville, Md.)
    - Woody Creek quadrangle (V. L. Freeman, D)
  - Connecticut:
    - Connecticut cooperative mapping program (L. R. Page, Boston, Mass.)
    - Taconic sequence (E-an Zen, W)

Geologic mapping--Continued

- Map scale 1 inch to 1 mile, and larger--Continued
  - District of Columbia, Washington metropolitan area (H. W. Coulter, C. F. Withington, W)
  - Florida, Attapulgus-Thomasville area, fuller's earth deposits (S. H. Patterson, Beltsville, Md.)
  - Georgia, Attapulgus-Thomasville area, fuller's earth deposits (S. H. Patterson, Beltsville, Md.)
  - Idaho:
    - Alpine quadrangle (H. F. Albee, c, Salt Lake City, Utah)
    - Bayhorse area (S. W. Hobbs, D)
    - Boulder Mountains (C. M. Tschanz, D)
    - Goat Mountain quadrangle (M. H. Staatz, D)
    - Grouse quadrangle (B. A. Skipp, D)
    - Hawley Mountain quadrangle (W. J. Mapel, D)
    - Henrys Lake area (I. J. Witkind, D)
    - Montour quadrangle (H. E. Malde, D)
    - Mt. Spokane quadrangle (A. E. Weissenborn, Spokane, Wash.)
    - Palisades Dam quadrangle (D. A. Jobin, c, D)
    - Patterson quadrangle (E. T. Ruppel, D)
    - Poker Peak quadrangle (H. F. Albee, c, Salt Lake City, Utah)
    - Upper Valley quadrangle (R. L. Rioux, c, W)
    - Washington Peak quadrangle (D. A. Seeland, D)
    - Wood River district (W. E. Hall, M)
    - Yandell Springs quadrangle (D. E. Trimble, D)
    - Yellow Pine quadrangle (B. F. Leonard, D)
  - Indiana:
    - Ohio River Quaternary (M. P. Weiss, DeKalb, Ill.)
    - Ohio River valley, Quaternary geology (L. L. Ray, W)
  - Kentucky:
    - Appalachian folded belt, southern part (L. D. Harris, Knoxville, Tenn.)
    - Kentucky cooperative mapping program (P. W. Richards, Lexington)
  - Maine:
    - Blue Hill quadrangle (D. B. Stewart, W)
    - Castine quadrangle (D. B. Stewart, W)
    - Chain Lakes area (E. L. Boudette, Hanover, N.H.)
    - Southern Aroostook County (L. Pavlides, W)
    - The Forks quadrangle (F. C. Canney, D)
  - Maryland:
    - Cecil County (L. C. Conant, W)
    - Delmarva Peninsula (J. P. Owens, Beltsville, Md.)
    - New Windsor quadrangle (G. W. Fisher, Beltsville, Md.)
    - Washington, D. C., metropolitan area (H. W. Coulter, C. F. Withington, W)
  - Massachusetts:
    - Massachusetts cooperative mapping program (L. R. Page, Boston)
    - Taconic sequence (E-an Zen, W)
  - Michigan:
    - Gogebic Range, eastern (V. A. Trent, W)
    - Gogebic Range, western part (R. G. Schmidt, W)
    - Greenland and Rockland quadrangles (J. W. Whitlow, Beltsville, Md.)
    - Isle Royale National Park (N. K. Huber, M)
    - Western Negaunee quadrangle (G. C. Simmons, D)
  - Montana:
    - Barker quadrangle (I. J. Witkind, D)
    - Bearpaw Mountains, petrology (B. C. Hearn, Jr.)
    - Black Butte 7½-minute quadrangle (L. M. McGrew, Laramie, Wyo.)

Geologic mapping--Continued
Map scale 1 inch to 1 mile, and larger--Continued
Montana--Continued
Black John Coulee quadrangle (G. D. Mowat, c, Billings)
Butte North quadrangle (H. W. Smedes, D)
Cooke City quadrangle (J. E. Elliott, D)
Craig quadrangle (R. G. Schmidt, W)
Crazy Mountains Basin (B. A. Skipp, D)
Diamond City No. 3 quadrangle (W. B. Myers, D)
Hardy quadrangle (K. S. Soward, c, Great Falls)
Henrys Lake area (I. J. Witkind, D)
Holter Lake quadrangle (G. D. Robinson, D)
Jordan 2 NE and SE quadrangles (G. D. Mowat, c, Billings, Mont.)
Lemhi Pass quadrangle (M. H. Staatz, D)
Little Prickly Pear 15-minute quadrangle (G. D. Robinson, D)
Melrose phosphate field (G. D. Fraser, c, D)
Neihart 1 quadrangle (W. R. Keefer, D)
Northern Pioneer Range, geologic environment E-an Zen, W)
Ringling quadrangle (L. M. McGrew, Laramie, Wyo.)
Rocky Reef quadrangle (K. S. Soward, c, Great Falls)
Sun River Canyon area (M. R. Mudge, D)
Wise River quadrangle (G. D. Fraser, c, D)
Wolf Creek area, petrology (R. G. Schmidt, W)
Nevada:
Bellevue Peak quadrangle (T. B. Nolan, W)
Carlin region (J. F. Smith, Jr., D)
Dun Glen quadrangle (D. H. Whitebread, M)
Eureka quadrangle (T. B. Nolan, W)
Jordan Meadow and Disaster Peak quadrangles (R. C. Greene, M)
Kobeh Valley (T. B. Nolan, W; C. W. Merriam, M)
Lewis district (T. J. Armbrustmacher, M)
Lida Wash quadrangle (K. B. Krauskopf, M)
Midas-Jarbidge area (R. R. Coats, M)
Montello area (L. H. Godwin, c, M)
Nevada Test Site:
Geologic studies (E. B. Ekren, D)
Site studies (P. P. Orkild, D)
Pinto Summit quadrangle (T. B. Nolan, W)
Spruce Mountain quadrangle (G. D. Fraser, c, D)
Wildcat Peak quadrangle (E. H. McKee, M)
New Hampshire, Milford 15-minute quadrangle, surficial (C. Koteff, Boston, Mass.)
New Jersey, Delaware River basin, lower part (J. P. Owens, Beltsville, Md.)
New Mexico:
Acoma area (C. H. Maxwell, D)
Cretaceous stratigraphy, San Juan basin (E. R. Landis, D)
Gallup West quadrangle (J. E. Fassett, c, Farmington)
Madrid quadrangle (G. O. Bachman, D)
Manuelito quadrangle (J. E. Fassett, c, Farmington)
Manzano Mountains (D. A. Myers, D)
Raton coal basin, western part (C. L. Pillmore, D)
Rowe and Bull Canyon quadrangles (R. B. Johnson, D)
Samson Lake quadrangle (J. E. Fassett, c, Farmington)
Twin Butte quadrangle (J. E. Fassett, c, Farmington)
Valles Mountains, petrology (R. L. Smith, W)
Wingate-Thoreau area (C. T. Pierson, D)

Geologic mapping--Continued
Map scale 1 inch to 1 mile, and larger--Continued
New York:
Pope Mills and Richville quadrangles (C. E. Brown, W)
Taconic sequence (E-an Zen, W)
North Carolina:
Central Piedmont (A. A. Stromquist, D)
Northern slate belt, North Carolina-Virginia (Lynn Glover, Beltsville, Md.)
North Dakota:
Clark Butte 15-minute quadrangle (G. D. Mowat, c, Billings, Mont.)
Dengate quadrangle (C. S. V. Barclay, c, D)
Glen Ullin quadrangle (C. S. V. Barclay, c, D)
Heart Butte and Heart Butte NW quadrangles (E. V. Stephens, c, D)
New Salem quadrangle (H. L. Smith, c, D)
North Almont quadrangle (H. L. Smith, c, D)
White Butte 15-minute quadrangle (K. S. Soward, c, Great Falls, Mont.)
Pennsylvania:
Allentown 15-minute quadrangle (A. A. Drake, Jr., W)
Anthracite region, flood control (M. J. Bergin, W)
Claysville-Avella area (S. P. Schweinfurth, W)
Delaware River basin, lower part (J. P. Owens, Beltsville, Md.)
Hyndman area (W. de Witt, Jr., Beltsville, Md.)
Mather-Garards Fort area (B. H. Kent, D)
Middle Delaware basin (A. A. Drake, Jr., W)
Southern anthracite field (G. H. Wood, Jr., W)
Waynesburg-Oak Forest area (J. B. Roen, Beltsville, Md.)
Western Middle anthracite field (H. Arndt, W)
Wind Gap and adjacent quadrangles (J. B. Epstein, Beltsville, Md.)
South Dakota:
Hill City pegmatite area (J. C. Ratté, D)
Northern Black Hills (R. W. Bayley, M)
Rapid City area (J. M. Cattermole, D)
Tennessee:
Appalachian folded belt, southern part (L. D. Harris, Knoxville)
Midway belt, western part of State (W. S. Parks, w, Nashville)
Texas, coastal plain, geophysical and geological studies (D. H. Eargle, Austin)
Utah:
Basin Canyon quadrangle (F. Peterson, c, D)
Big Hollow Wash quadrangle (F. Peterson, c, D)
Bingham Canyon district (E. W. Tooker, M)
Blackburn Canyon quadrangle (F. Peterson, c, D)
Butler Valley quadrangle (W. E. Bowers, c, D)
Canaan Creek quadrangle (H. D. Zeller, c, D)
Canaan Peak quadrangle (W. E. Bowers, c, D)
Carcass Canyon quadrangle (H. D. Zeller, c, D)
Coal-mine bumps (F. W. Osterwald, D)
Collet Top quadrangle (H. D. Zeller, c, D)
Crawford Mountains (W. C. Gere, c, Los Angeles, Calif.)
Cummings Mesa NE and SE quadrangles (F. Peterson, c, D)
Dave Canyon quadrangle (H. D. Zeller, c, D)
Death Ridge quadrangle (H. D. Zeller, c, D)

Geologic mapping--Continued
Map scale 1 inch to 1 mile, and larger--Continued
Utah--Continued
East-of-the-Navajo quadrangle (F. Peterson, c, D)
Fourmile Bench quadrangle (W. E. Bowers, c, D)
Gilbert Peak 1 NE quadrangle (E. M. Schell, c, Billings, Mont.)
Griffin Point quadrangle (W. E. Bowers, c, D)
Gunsight Butte SW ¼ quadrangle (F. Peterson, c, D)
Henrieville quadrangle (W. E. Bowers, c, D)
Horse Mountain quadrangle (W. E. Bowers, c, D)
Jessen Butte quadrangle (E. M. Schell, c, Billings, Mont.)
Needle Eye Point quadrangle (H. D. Zeller, c, D)
Oak City area (D. J. Varnes, D)
Ogden 4 NW quadrangle (R. J. Hite, c, D)
Park City district (C. S. Bromfield, D) Pete's Cove quadrangle (H. D. Zeller, c, D)
Phil Pico Mountain quadrangle (J. R. Dyni, c, D)
Pine Lake quadrangle (W. E. Bowers, c, D)
Raft River Mountains (R. R. Compton, Stanford, Calif.)
Salt Lake City and vicinity (R. Van Horn, D)
San Francisco district (D. M. Lemmon, M)
Seep Flat quadrangle (H. D. Zeller, c, D)
Sheeprock Mountains, West Tintic district (H. T. Morris, M)
Ship Mountain Point quadrangle (H. D. Zeller, c, D)
Sooner Bench quadrangle (F. Peterson, c, D)
Sunset Flat quadrangle (F. Peterson, c, D)
Upper Valley quadrangle (W. E. Bowers, c, D)
Vernal phosphate area (E. M. Schell, c, Billings, Mont.)
Willard Peak area (M. D. Crittenden, Jr., M)
Virginia:
Appalachian folded belt, southern part (L. D. Harris, Knoxville, Tenn.)
Big A Mountain quadrangle (R. L. Miller, W)
Delmarva Peninsula (J. P. Owens, Beltsville, Md.)
Fairfax quadrangle (P. M. Hanshaw, W)
Northeast area (L. Pavlides, Beltsville, Md.)
Northern slate belt, North Carolina-Virginia (Lynn Glover, Beltsville, Md.)
Quantico 15-minute quadrangle (R. B. Mixon, Beltsville, Md.)
Washington, D.C., metropolitan area (H. W. Coulter, W)
Washington:
Chewelah No. 4 quadrangle (F. K. Miller, M)
Glacier Park area (F. W. Cater, D)
Loomis quadrangle (C. D. Rinehart, M)
Mt. St. Helens and Spirit Lake quadrangles, (C. A. Hopson, Santa Barbara, Calif.)
Mt. Spokane quadrangle (A. E. Weissenborn, Spokane)
Newport 30-minute quadrangle (F. K. Miller, M)
Olympic Peninsula, eastern part (W. M. Cady, D)
Puget Sound Basin (D. R. Mullineaux, D)
Stevens County (R. G. Yates, M)
Togo Mountain quadrangle (R. C. Pearson, D)
Twin Lakes quadrangle (G. E. Becraft, W)
Wisconsin:
Black River Falls and Hatfield quadrangles (H. Klemic, W)
Lead-zinc district (W. S. West, Platteville)

Geologic mapping--Continued
Map scale 1 inch to 1 mile, and larger--Continued
Wyoming:
Albany and Keystone quadrangles (M. E. McCallum, Fort Collins, Colo.)
Alkali Butte quadrangle (M. W. Reynolds, D)
Alpine quadrangle (H. F. Albee, c, Salt Lake City, Utah)
Badwater Creek (R. E. Thaden, D)
Bailey Lake quadrangle (M. L. Schroeder, c, D)
Browns Hill quadrangle (C. S. V. Barclay, c, D)
Bull Creek quadrangle (M. L. Schroeder, c, D)
Cache Creek quadrangle (D. A. Jobin, c, D)
Camp Davis quadrangle (D. A. Jobin, c, D)
Cokeville and adjacent quadrangles (W. W. Rubey, Los Angeles, Calif.)
Cottonwood Rim quadrangle (C. S. V. Barclay, c, D)
Creston Junction quadrangle (R. B. Sanders, c, D)
Deer Creek quadrangle (D. A. Jobin, c, D)
Devils Tooth quadrangle (W. G. Pierce, M)
Ferry Peak quadrangle (D. A. Jobin, c, D)
Gas Hills uranium district (F. C. Armstrong, Spokane, Wash.)
Grand Teton National Park (J. D. Love, Laramie)
Grieve Reservoir quadrangle (C. S. V. Barclay, c, D)
Hoback Peak quadrangle (D. A. Jobin, c, D)
Hulett Creek (C. H. Maxwell, D)
Jackson 7½-minute quadrangle (H. F. Albee, c, Salt Lake City, Utah)
Ketchum Buttes quadrangle (C. S. V. Barclay, c, D)
Lander area phosphate reserve (W. L. Rohrer, c, D)
Monarch quadrangle, (B. E. Barnum, c, D)
Observation Peak quadrangle (H. F. Albee, c, Salt Lake City, Utah)
Oil Mountain quadrangle (W. H. Laraway, c, Casper)
Palisades Peak quadrangle (D. A. Jobin, c, D)
Palisades Reservoir quadrangle (H. F. Albee, c, Salt Lake City, Utah)
Pickle Pass quadrangle (D. A. Jobin, c, D)
Pilot Peak quadrangle (W. G. Pierce, M)
Pine Creek quadrangle (D. A. Jobin, c, D)
Pine Mountain quadrangle (W. H. Laraway, c, Casper)
Ranchester quadrangle (B. E. Barnum, c, D)
Reid Canyon quadrangle (W. H. Laraway, c, Casper)
Riner quadrangle (R. B. Sanders, c, D)
Sagebrush Park quadrangle (L. J. Schmitt, Jr., D)
Savery quadrangle (C. S. V. Barclay, c, D)
Sheridan Pass quadrangle (W. L. Rohrer, c, D)
Spence-Kane area (R. L. Rioux, c, W)
Square Top Butte quadrangle (W. H. Laraway, c, Casper)
Stewart Peak quadrangle (D. A. Jobin, c, D)
Sweetwater County, Green River Formation (W. C. Culbertson, D)
Taylor Mountain quadrangle (M. L. Schroeder, c, D)
Tullis quadrangle, (C. S. V. Barclay, c, D)
Wapiti quadrangle (W. G. Pierce, M)
Wind River Basin, regional stratigraphy (W. R. Keefer, D)
Yellowstone National Park, north and south-central part, pre-Tertiary rocks (W. R. Keefer and E. T. Ruppel, D)
Puerto Rico (R. P. Briggs, San Juan)

Helium, Rocky Mountains region natural gases (D. E. Ward, D)

Hydraulics, ground water:

- Applicability of the unsaturated flow theory to the phenomena of drainage and infiltration (J. Rubin, w, M)
- Computer analysis—ground-water problems (S. S. Papadopulos, w, W)
- Mechanics of aquifer systems (J. F. Poland, w, Sacramento, Calif.)
- Mechanics of ground-water flow (G. F. Pinder w, W)
- Permeability distribution study—Atlantic Coastal Plain (P. M. Brown, w, Raleigh, N.C.)
- Regional hydrologic system analysis—Hydrodynamics (R. R. Bennett, w, W)
- Regional hydrologic system analysis—permeability distribution (J. D. Bredehoeft, w, W)
- Response of well-aquifer systems to explosions (W. W. Dudley, w, D)
- Theory of multiphase flow—applications (E. P. Weeks, w, D)
- Transport processes in fluid flows (A. Ogata, w, Honolulu, Hawaii)
- Velocities of ground water and radionuclides at the Amargosa tracer site, Nevada (D. B. Grove, E. H. Cordes, w, D)
- Kansas:
  - Artificial recharge of ground water, central part of State (J. B. Gillespie, Jr., w, Lawrence)
  - Gravity flow of water in soils and aquifers, western part of State (R. C. Prill, w, Garden City)
- New Mexico:
  - Effects of detonations (F. C. Koopman, w, Albuquerque)
  - Water conditions in Carlsbad Caverns (F. C. Koopman, w, Albuquerque)
- New York, influx to Lake Ontario (E. C. Rhodehamel, w, Albany)

Hydraulics, surface flow:

- Channel characteristics, California:
  - Channel capacity, San Joaquin River (K. W. Lee, w, Sacramento)
  - Feather River channel capacity (J. Blodgett, w, Sacramento)
  - Mokelumne River channel capacity (J. Blodgett, w, Sacramento)
- Channel characteristics, Western United States, mean annual runoff and flood flows as related to channel geometry (E. R. Hedman, w, Lawrence, Kans.)
- Channel constrictions:
  - Bridge-site studies, Alaska (J. M. Childers, w, Anchorage)
  - Bridge-site verifications, Louisiana (B. L. Neely, w, Baton Rouge)
  - Hydraulic criteria for design of bridges and culverts (K. W. Causseaux, w, Tuscaloosa, Ala.)
  - Hydraulic performance of bridges (B. E. Colson, w, Jackson, Miss.)
  - Scour research at bridge piers, Alaska (V. W. Norman, w, Anchorage, Alaska).
  - Verification of hydraulic techniques (W. J. Randolph, w, Nashville, Tenn.)
- Flow characteristics:
  - Alluvial channel flow (C. F. Nordin, Jr., w, Fort Collins, Colo.)
  - Cooper River environmental study (F. A. Johnson, w, Columbia, S.C.)

Hydraulics, surface flow--Continued

- Flow characteristics--Continued
  - Dispersion by turbulent flow in open channels (N. Yotsukura, w, W)
  - Dispersion processes in esturaries and rivers (H. B. Fischer, w, University of California, Berkeley)
  - Effect of temperature on winter runoff (W. D. Simons, w, M)
  - Floods from small drainages, California (A. O. Waananen, w, M)
  - Hydraulic geometry of streams, Kansas (C. V. Burns, Lawrence, Kans.)
  - Hydraulics of Port Royal Sound estuarine system (F. A. Johnson, w, Columbia, S.C.)
  - Mechanics of flow structure and fluid resistance—movable boundary (R. S. McQuivey, w, Fort Collins, Colo.)
  - Mechanics of fluid resistance (H. J. Tracy, w, Atlanta, Ga.)
  - Numerical simulation of hydrodynamic phenomena by digital computer (Chintu Lai, w, W)
  - Runoff model, Sacramento River, Calif. (J. C. Blodgett, w, Sacramento)
  - Unsteady flow and saline intrusions in rivers and estuaries (R. A. Baltzer, w, W)
- Laboratory studies:
  - Grain-size distribution and bedload transport (G. Williams, w, W)
  - Time-of-travel studies:
    - Indiana (R. E. Hoggatt, w, Indianapolis)
    - Maryland (K. R. Taylor, w, Parkville)
    - New York (L. A. Wagner, w, Albany)
- *See also* Hydrologic instrumentation.

Hydrologic-data collection and processing:

- Bathymetry and sediments, Rhode River estuary, Anne Arundel County, Md. (R. L. Nace, A. Sinnott, w, W)
- Data storage, retrieval, and application by digitial-computer techniques (J. M. McNellis, D. V. Maddy, w, Lawrence, Kans.)
- Drainage-area determinations:
  - Indiana (R. E. Hoggatt, w, Indianapolis)
  - Kentucky (H. C. Beaber, w, Louisville)
  - Mississippi (J. D. Shell, w, Jackson)
  - New Jersey, for gazetteer of streams (E. G. Miller, w, Trenton)
  - Tennessee (G. H. Wood, w, Nashville)
  - Texas (P. H. Holland, w, Austin)
- Hydrologic probability models (W. H. Kirby, w, W)
- Rapid transmission and dissemination of current data (J. E. McCall, w, Trenton, N.J.)
- River-mile determinations, South Carolina (W. T. Utter, w, Columbia)
- Sediment loads in streams—methods used in measurement and analysis (J. V. Skinner, w, Minneapolis, Minn.)
- Statistical inferences (E. J. Gilroy, w, W)
- Water budget of North America (A. Wilson, w, W)
- Water use data, 1970 (R. Murray, w, W)
- Great Basin, selected hydrologic data (D. Price, w, Salt Lake City, Utah)
- Colorado, statistical design of data collection network (R. R. Luckey, w, D)

Marine geology:
- Marine mineral resources, worldwide (F. H. Wang, M)
- Atlantic Continental Shelf:
  - Geologic studies (J. S. Schlee, Woods Hole, Mass.)
  - Carolinas nearshore, geologic studies (J. S. Schlee, Woods Hole, Mass.)
  - Gulf of Maine section, geologic studies (J. S. Schlee, Woods Hole, Mass.)
  - Resources conservation (J. S. Schlee, Woods Hole, Mass.)
- Gulf of Mexico:
  - Caribbean region (L. Garrison, Corpus Christi, Tex.)
  - Florida Continental Shelf gravity (H. Krivoy, Corpus Christi, Tex.)
  - Geochemistry of sediments (C. W. Holmes, Corpus Christi, Tex.)
  - Louisiana Continental Shelf (H. L. Berryhill, Jr., Corpus Christi, Tex.)
- Pacific island studies (G. Corwin, W)
- Pacific Ocean, biostratigraphy, deep ocean (J. D. Bukry, La Jolla, Calif.)
- Alaska:
  - Arctic coastal marine processes (E. Reimnitz, M)
  - Beaufort-Chuckchi Sea Continental Shelf (Arthur Grantz, M)
  - Bering Shelf (D. M. Hopkins, M)
  - Continental shelf resources (D. M. Hopkins, M)
  - Gulf of Alaska (D. M. Hopkins, M)
  - Seward Peninsula, nearshore (D. M. Hopkins, M)
  - Tectonic history (R. von Huene, M)
- California:
  - Channel Islands and basins (J. E. Schoellhamer, M)
  - Continental margin, central part (J. E. Schoellhamer, M)
  - Effects of Quaternary sea level oscillations on sedimentation in coastal valleys in central and northern California (R. J. Janda, w, Menlo Park)
  - La Jolla marine geology laboratory (G. W. Moore, La Jolla)
  - Los Angeles area, continental shelf (H. C. Wagner, M)
  - Monterey Bay (H. G. Greene, M)
  - Northern part, offshore black sands (G. W. Moore, La Jolla)
  - San Francisco Bay (D. S. McCulloch, M)
  - Southern California, geology and geophysics (G. W. Moore, La Jolla)
- North Carolina, continental shelf (H. L. Berryhill, Jr., Corpus Christi, Tex.)
- Oregon, land-sea transect, Newport (P. D. Snavely, Jr., M)
- Oregon-California, black sands (H. E. Clifton, M; G. W. Moore, La Jolla, Calif.)
- Oregon-Washington, nearshore (P. D. Snavely, Jr., M)
- Puerto Rico cooperative program (L. E. Garrison, M)
- Texas Continental Shelf stratigraphy (K. A. Dickinson, Corpus Christi, Tex.)
- Virgin Islands, Tektite II (H. E. Clifton, M)

Marine hydrology:
- Maryland, effects of water quality changes on biota in estuaries (R. L. Cory, J. W. Nauman, w, W)
- New Jersey:
  - Recording of maximum tides (S. J. Stankowski, S. L. Laskowski, w, Trenton)
  - Tidal stage, discharge and velocity studies (A. C. Lendo, w, Trenton)
- Washington, influence of industrial and municipal wastes on estuarine and offshore water quality (W. S. Haushild, w, Tacoma)

Marine hydrology--Continued
- Washington-Oregon, movement of radionuclides in the Columbia River estuary (D. W. Hubbell, w, Portland, Oreg.)
- *See also* Hydrology, surface water; Quality of water; Radioactive materials, transport in water; Salt-water intrusion.

Mercury:
- Geochemistry (A. P. Pierce, D)
- Mercury deposits and resources (E. H. Bailey, M)
- California, Coast Range ultramafic rocks (E. H. Bailey, M)
- Nevada-Oregon, Cordero district (R. C. Greene, M)

Meteorites. *See* Extraterrestrial studies.

Mineral and fuel resources—compilations and topical studies:
- Alteration study, Summitville district, Colorado (R. E. Van Loenen, D)
- Arctic mineral resources investigations (W. P. Brosgé, M)
- Colorado, central, geologic control of ore deposits (O. L. Tweto, D)
- Colorado mineral provinces (W. P. Pratt, D)
- Colorado Plateau (R. P. Fischer, D)
- Information bank, computerized (J. A. Calkins, W)
- Iron resources studies, United States (H. Klemic, W)
- Lightweight-aggregate resources, nationwide (A. L. Bush, D)
- Metallogenic maps, United States (P. W. Guild, W)
- Metals in volcaniclastic rocks (D. A. Lindsey, D)
- Mineral deposit controls, central states (A. V. Heyl, Jr., D)
- Mineral-resources map, Utah (L. S. Hilpert, Salt Lake City)
- Mineral resources surveys:
  - Northern Wisconsin (C. E. Dutton, Madison)
  - Northwestern United States (A. E. Weissenborn, Spokane, Wash.)
  - Primitive and Wilderness Areas:
    - Absaroka Primitive Area, Mont. (H. Wedow, Knoxville, Tenn.)
    - Beartooth Primitive Area, Mont. and Wyo. (F. S. Simons, D)
    - Chiricahua Wilderness Area, Ariz. (H. D. Drewes, D)
    - Cloud Peak Primitive Area, Wyo. (T. H. Kiilsgaard, W)
    - Eagle Cap Wilderness Area, Oreg. (P. L. Weiss, Spokane, Wash.)
    - Gila Primitive Area, N. Mex. (J. C. Ratté, D)
    - High Sierra Primitive Area, Calif. (J. G. Moore, M)
    - Idaho Primitive Area, Idaho (F. W. Cater, D)
    - Lincoln Back Country Area, Mont., proposed (M. R. Mudge, D)
    - Mount Zirkel Wilderness Area, Colo. (G. L. Snyder, D)
    - North Absaroka Wilderness Area, Wyo. (W. H. Nelson, M)
    - Salmon-Trinity Alps Primitive Area, Calif. (P. E. Hotz, M)
    - San Pedro Parks Wilderness Area, N. Mex. (E. S. Santos, D)
    - Wilson Mountains Primitive Area, Colo. (C. S. Bromfield, D)
  - Puerto Rico (D. P. Cox, Santurce)
  - Southeastern United States (R. A. Laurence, Knoxville, Tenn.)
- Nevada, igneous rocks and related ore deposits (M. L. Silberman, M)
- Nonmetallic deposits, mineralogy (B. M. Madsen, M)
- Peat resources, Northeastern States (C. C. Cameron, W)
- Resource analysis (V. E. McKelvey, W)
- Resource data storage and retrieval (R. A. Weeks, W)
- Resource study techniques (R. A. Weeks, W)

Saline minerals--Continued
New Mexico, Carlsbad potash and other saline deposits (C. L. Jones, M)
Wyoming, Sweetwater County, Green River Formation (W. C. Culbertson, D)
Water in the central limestone region of St. Croix, U.S. Virgin Islands (T. M. Robison, w, San Juan, P.R.)

Salt-water intrusion:
California, ground water, Orange County analog model (W. F. Hardt, w, Garden Grove)
Florida, Dade County and city of Miami (F. W. Meyer, w, Miami)
Georgia:
Brunswick area (E. A. Zimmerman, w, Brunswick)
Savannah area (H. B. Counts, w, Atlanta)
Puerto Rico, salinity reconnaissance and monitoring system, south coast (J. R. Diaz, w, San Juan)
Washington, reconnaissance of sea-water encroachment (K. L. Walters, w, Tacoma)
See also Marine hydrology; Quality of water.

Sedimentation:
Behavior of alluvial channels (T. Maddock, Jr., w, Tucson, Ariz.)
General studies of erosion and sedimentation, and evaluation of erosion-control practices (N. J. King, w, D)
Measurement of river bedload, rivers near Pinedale, Wyo. (L. B. Leopold, w, W)
Mechanics of flow and sediment transport (J. P. Bennett, w, Fort Collins, Colo.)
Sources, movement, and distribution of sediment in a small watershed (M. G. Wolman, w, Baltimore, Md.)
Transport properties of natural clays (R. G. Wolff, w, W)
Western States, evaluation and development of methods for classification of arid and semiarid watersheds (L. M. Shown, w, D)
California:
Bolinas Lagoon hydrology (J. R. Ritter, w, M)
Channel changes, Big Tujunga Wash (K. M. Scott, w, Garden Grove)
Debris potential, Ventura County (K. M. Scott, w, Garden Grove)
Fluvial sediment transport to San Francisco Bay (G. Porterfield, w, M)
Limnology, erosion potential, Zayante Creek (W. M. Brown, w, M)
Mad River, Butler Valley (W. M. Brown, w, M)
Redwoods National Park (J. R. Ritter, w, M)
Sediment character of California streams (J. R. Crippen, w, M)
Sediment in western tributaries of Sacramento River (J. R. Crippen, w, M)
Sediment transport:
Eel River basin (W. M. Brown, w, M)
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South coast streams (C. Kroll, w, Garden Grove)
Sediment yield, Trinity River (J. M. Knott, w, M)
Colorado, Badger Wash area, effect of grazing exclusion (G. C. Lusby, w, D)
Indiana, reconnaissance of sediment yields in streams (R. A. Pettijohn, w, Indianapolis)
Louisiana, Bayou Lafourche channel building processes (W. H. Doyle, w, Baton Rouge)

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Nevada, relation to urbanization at Incline Village, Lake Tahoe basin (P. A. Glancy, w, Carson City)
New Jersey:
Sediment investigations, Delaware River basin (L. J. Mansue, w, Trenton)
Stony Brook watershed, fluvial sedimentation (L. J. Mansue, w, Trenton)
New Mexico, reservoir trap efficiency (J. D. Dewey, w, Albuquerque)
North Carolina, preliminary report on sediment in streams (H. E. Reeder, w, Raleigh)
Ohio, sediment characteristics of Ohio streams (R. F. Flint, w, Columbus)
Oregon, Quaternary sedimentation at the marine-fluvial interface, southwestern Oregon (R. J. Janda, w, M)
Pennsylvania:
Bixler Run watershed, hydrology and sedimentation (L. A. Reed, w, Harrisburg)
Corey Creek and Elk Run watershed (L. A. Reed, w, Harrisburg)
Evaluation of erosion-control measures used in highway construction (L. A. Reed, w, Harrisburg)
Susquehanna River basin, fluvial sediment reconnaissance (L. A. Reed, w, Harrisburg)
Texas, Laguna Madre-Padre Island (K. A. Dickinson, Corpus Christi)
Washington, Snohomish River basin, fluvial sediment transport (L. M. Nelson, w, Tacoma)
See also Geochronology; Hydraulics, surface flow, channel characteristics; Hydrologic-data collection and processing; Radioactive materials, transport in water; Stratigraphy and sedimentation; Urbanization, hydrologic effects.

Sedimentation, reservoirs:
California, sediment yield, Dos Rios Reservoir (J. Knott, w, M)
Maryland, North Branch Rock Creek near Rockville (W. J. Davis, w, College Park)
Utah, Paria River basin, Sheep Creek near Tropic sediment barrier (G. C. Lusby, w, D)

Selenium. *See* Minor elements.

Silver. *See* Heavy metals; Lead, zinc, and silver.

Soil moisture:
Effects of depth and duration of floodwater spreading on vegetation in northeast Montana (F. A. Branson, w, D)
Hydrologic implications of the physical and chemical characteristics of soils (R. F. Miller, w, D)
New York, relation of soil moisture and water content of snow to runoff (E. C. Rhodehamel, w, Albany)
Thermal conductivity of soil, instruments (C. R. Daum, w, d)
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Spectroscopy:
Mobile spectrographic laboratory (A. P. Marrinzino, D)
Spectrographic analytical services and research (A. W. Helz, W; A. T. Myers, D; H. Bastron, M)
X-ray spectroscopy (H. J. Rose, Jr., W; H. Bastron, M)

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Missouri (A. Homyk, w, Rolla)

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Ground water:
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Regional ground-water study of the Ohio River basin (R. E. Bloyd, w, St. Louis, Mo.)
Lower Colorado River, ground-water return flows to (O. J. Loeltz, w, Yuma, Ariz.)
Lower Mississippi River type I framework study (E. H. Boswell, w, Jackson, Miss.)
Plant ecology, hydrologic effects of conversion from pinyon-juniper woodland to grassland (J. R. Owen, w, D)
Public domain:
Great Basin, influence of hydrology and paleohydrology on design of land use programs (C. T. Snyder, w, M)
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Pacific coast region—Water-supply exploration (R. E. Smith, w, M)
Rocky Mountain region, water-supply exploration (N. J. King, w, D)
Western States, areal hydrology (G. C. Lusby, w, D)
Alabama (w, Tuscaloosa):
Hydrogeologic study of State (J. G. Newton)
Relation of oil and gas industry to water resources (M. E. Davis)
Water resources:
Coosa River basin, upper part (J. R. Harkins)
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Urban hydrology (R. C. Christensen)
Water use study (L. B. Peirce)
Alaska (w, Anchorage, except as noted otherwise):
Ground water, statewide water levels (A. J. Feulner)
Hydrology:
Anchorage area (W. W. Barnwell)
Greater Juneau Borough (J. A. McConaghy, Juneau)
Hydrologic environment of the Trans Alaska Pipeline System (TAPS) (J. M. Childers)
Kenai Peninsula Borough (G. S. Anderson, S. H. Jones)
Municipal water-supply investigations (District staff)
Petersburg (J. A. McConaghy, Juneau)
Water supplies for village schools (A. J. Feulner)
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Arizona (w, Tucson):
Hydrogeologic reconnaissance of lower Tonto Creek basin (H. H. Schumann)
Ground water:
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Beardsley area (W. Kam)
Big Sandy Valley (E. S. Davidson)
Coconino County, southern part (E. H. McGavock)
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Reconnaissance study of water supply of Lake Mead Recreational Area (C. B. Bentley)
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Hydrology, alluvial basins (M. E. Cooley)
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Arkansas (w, Little Rock):
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Ground water, ground-water hydrology of alluvial valleys of Arkansas and Verdigris Rivers (M. S. Bedinger)
California (w, Menlo Park, except as noted otherwise):
Circulation patterns and sediment transport in San Francisco Bay estuary and the adjacent ocean (T. J. Conomos)
Computer technology in water-resources studies:
Dispersion of heat in stratified flow (J. G. Weil)
Modeling and simulation of surface-water quality (S. M. Zand)
Reservoir yield and bank storage relationships—computer applications (T. H. Thompson)
Geochemistry of water, chemical reactions at mineral surfaces (J. D. Hem)
Ground water:
Antelope Valley area (G. A. Miller)
Aquicludes in San Joaquin Valley (G. L. Bertoldi, Sacramento)
Aquifer evaluation, Yucca-Joshua (R. E. Lewis, Garden Grove)
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Ground-water network criteria (L. C. Dutcher)
Hollister-San Juan Bautista area (C. Kilburn)
Indian Wells Valley area (G. A. Miller, Garden Grove)
Indian Wells Valley digital model (R. M. Bloyd, Jr., Garden Grove)
Irvine Ranch, artificial recharge (J. A. Singer, Garden Grove)
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Mojave River analog model (W. F. Hardt, Garden Grove)
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Pumpage, Monterey County (K. S. Muir)
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Quality degradation, Barstow area (G. A. Miller, Garden Grove)
Santa Clara Valley model (P. R. Wood)
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Upper Coachella Valley, artificial recharge (S. J. Tyley, Garden Grove)
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Hydrology of Big Bear Lake (E. G. Pearson, Garden Grove)
Oak Glen water resources development (R. E. Lewis, Garden Grove)
Perris Valley urban hydrology (M. Busby, Garden Grove)
Relation between surface water and ground water, factors determining feasibility of artificial recharge (J. Rubin)
Surface water, temperature distribution in natural streams (J. C. Blodgett, Sacramento)
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Upper Santa Ana Canyon, reconnaissance (G. A. Irwin, Garden Grove)
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Surface-water hydrology, Hollenbeck River basin (F. R. Ruggles)
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Fort Lauderdale area, special studies (H. J. McCoy)
Peace and Alafia River basins (A. F. Robertson, Tampa)
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Ground-water hydrology, Pasco well-field area (W. C. Sinclair, Tampa)

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Loxahatchee Refuge area (A. L. Higer)
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Infiltration, Miami Canal (F. W. Meyer, w, Miami)
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A complete list of abstracts, papers, reports, and maps (exclusive of topographic maps) prepared by U.S. Geological Survey authors and published or otherwise released to the public during fiscal year 1971 (July 1, 1970–June 30, 1971) is given on the following pages. Publications are listed alphabetically by senior author. Because many Geological Survey authors collaborate with colleagues from outside the Survey in the preparation of reports published both by the Survey and by cooperating agencies and of articles in technical journals, not all the senior authors of the publications listed below are members of the U.S. Geological Survey.

Each citation is identified by an acquisition number that was used in computer compilation of the list (in the text, the first cipher of the number is replaced by the prefix "r"). References to this list are identified in the preceding text by author and acquisition number: for example, J. T. Abbott (r0287).

The list also includes a few publications that were not listed in "Geological Survey Research 1970" and earlier volumes.

00287 **Abbott, Jeffrey T.** Geology of Precambrian rocks and isotope geochemistry of shear zones in the Big Narrows area, northern Front Range, Colorado: U.S. Geol. Survey open-file report, 239 p., illus., tables, 1970.

Abel, John F., Jr. *See* Nichols, Thomas C., Jr. 01355

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00351 **Addicott, Warren O.** Biographical sketch of Leo G. Hertlein: Nautilus, v. 84, no. 2, p. 37-41, 1970.

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