

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

RESULTS OF—

Investigations in  
progress

Reports published  
in fiscal year 1970

Cooperating agencies

Geological Survey offices

# GEOLOGICAL SURVEY RESEARCH 1970

## Chapter A







# GEOLOGICAL SURVEY RESEARCH 1970

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GEOLOGICAL SURVEY PROFESSIONAL PAPER 700

*Significant results of investigations for fiscal year 1970, accompanied by short papers in the fields of geology, hydrology, and related sciences. Published separately as Chapters A, B, C, and D.*



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UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON: 1970

UNITED STATES DEPARTMENT OF THE INTERIOR

WALTER J. HICKEL, Secretary

GEOLOGICAL SURVEY

William T. Pecora, Director

# GEOLOGICAL SURVEY RESEARCH 1970

## Chapter A

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GEOLOGICAL SURVEY PROFESSIONAL PAPER 700-A

*A summary of recent significant scientific and economic results accompanied by a list of publications released in fiscal year 1970, 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 1970," the eleventh annual review of the economic and scientific work of the U.S. Geological Survey, consists of four chapters (A through D) of Professional Paper 700. 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 1970", beginning on page A299. The tables of contents for chapters B through D are listed on pages A293-A298 of this chapter.

Numerous Federal, State, county, and local agencies and other organizations and countries listed on pages A251-A256 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 1971," will be published as chapters of Professional Paper 750. 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
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*William T. Pecora*  
WILLIAM T. PECORA,  
*Director.*





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## REFERENCES

Text references are in three forms:

### W. J. Moore (p. C61-C69)

Refers to a short paper published in a chapter of "Geological Survey Research 1970." The letter preceding the page numbers identifies the chapter. The tables of contents for the short-paper chapters are on p. A293-A298.

### Herz, Valentine, and Iberall (r0422)

Refers to a publication released in fiscal year 1970 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. A299. (In the text, the prefix "r" replaces the first cipher of the acquisition numbers in the list.)

### Footnotes

Used for those publications that were released before or after fiscal year 1970, 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	kb_____	kilobars	$\mu$ cal_____	microcalories
A <sup>3</sup> _____	cubic angstroms	kg_____	kilograms	$\mu$ g_____	micrograms
acre-ft_____	acre-feet	km_____	kilometers	$\mu$ m _____	micrometers
atm_____	atmospheres	km <sup>2</sup> _____	square kilometers	$\mu$ mhos _____	micromhos
bbl_____	barrels	km <sup>3</sup> _____	cubic kilometers	$\mu$ r _____	microrontgens
B.P._____	Before Present	kwhr_____	kilowatt hours	N _____	normal (concentration)
b.y._____	billion years	l_____	liters	nm _____	nanometers
cal_____	calories	lb_____	pounds	pCi _____	picocuries
cfs_____	cubic feet per second	ln_____	logarithm (natural)	pH _____	pH (measure of hydrogen ion activity)
Ci_____	Curies	M_____	molar (concentration)	ppb _____	parts per billion
cm_____	centimeters	m_____	meters	ppm _____	parts per million
cm <sup>2</sup> _____	square centimeters	m <sup>3</sup> _____	cubic meters	psi _____	pounds per square inch
cm <sup>3</sup> _____	cubic centimeters	Mev_____	million (mega) electron volts	psia _____	pounds per square inch absolute
cu ft_____	cubic feet	mg_____	milligrams	sec _____	seconds
cu yd_____	cubic yards	mgal_____	milligals	sq ft _____	square feet
deg_____	degrees	mgd_____	million gallons per day	sq mi _____	square miles
fpd_____	feet per day	MHz_____	megahertz	T.U. _____	tritium units
fps_____	feet per second	mi_____	miles	VLF _____	very low frequency
ft_____	feet	ml_____	milliliters	wt _____	weight
g_____	grams	mm_____	millimeters	yr _____	years
gal_____	gallons	m $\mu$ _____	millimicrons		
gpd_____	gallons per day	Mw_____	megawatts		
gpm_____	gallons per minute	m.y._____	million years		
hr_____	hours	$\mu$ _____	microns		
in_____	inches				

## RESOURCES INVESTIGATIONS

SPECIAL AND TOPICAL MINERAL-  
RESOURCE PROGRAMS

## BASE, FERROUS, AND PRECIOUS METALS

## GENESIS OF BASE AND PRECIOUS METAL DEPOSITS

## Basin and Range province

*Bodie district, California.*—Detailed geochronologic studies in the Bodie district, Mono County, Calif., by M. L. Silberman and F. J. Kleinhampl showed that eruption of tuff breccia (host rocks for the ore deposits), subsequent intrusion of plugs, and, finally, emplacement of vein deposits took place in a comparatively short period of about one million years. Recognition of the partial separation in time of these events was possible because the ages obtained are discrete enough not to fall within the experimental precision of the K-Ar method used.

*Goldfield district, Nevada.*—The main mining district at Goldfield, in Esmeralda and Nye Counties, Nev., lies in a small part of a large area of hydrothermally altered Tertiary volcanic rocks that extends to the east and north of the town of Goldfield. Prealteration (predating formation of ore) rocks occupy much of the western and central parts of the Goldfield Hills and are generally of local origin, whereas most post-alteration units are more widespread and have source areas outside the Goldfield Hills. R. P. Ashley reported that chemical analyses show that the prealteration volcanic series is calc-alkalic, consisting largely of quartz latite, trachyandesite, and rhyodacite flows and tuffs, and is more silicic and (or) potassic than previously thought from modal and textural data. The entire sequence is characterized by unusually large amounts of barium and strontium; otherwise, the prealteration rocks at Goldfield are similar to other volcanic rocks of intermediate composition that are widely distributed in central and southern Nevada.

*Cortez-Buckhorn area, Nevada.*—The Cortex-Buckhorn area, Eureka and Lander Counties, Nev., was the locale of four episodes of igneous intrusion and extrusion from the Jurassic to the Miocene, according to J. D. Wells, J. E. Elliott, and J. D. Obradovich. The

earliest occurred in the Jurassic (150 m.y. ago) and is represented by the Mill Canyon stock of quartz monzonitic and granodioritic composition and associated porphyritic granodiorite and alaskite dikes; the granodiorite had been considered to be a quartz porphyry of Tertiary age. The second episode occurred during the Oligocene (34.6 m.y. ago) and is represented by the rhyolitic Caetano Tuff and quartz porphyry dikes. The third episode is represented by basaltic andesite flows and diabase dikes that were emplaced during the Miocene (16.3 m.y. ago); previously they had been considered to be Pliocene. The final episode is represented by rhyolite flows and intrusives emplaced during the Miocene (15.3 m.y. ago); also previously considered to be Pliocene. Variations in the trace-element content of the intermediate to silicic rocks can, in general, be correlated with their chemical differentiation and are consistent with published values for average rocks. However, the Miocene rhyolite contains unusually large amounts of lead (70 ppm), beryllium (10 ppm), yttrium (70 ppm), niobium (30 ppm), tin (20 ppm), and fluorine (0.44 percent) and is depleted in barium (20 ppm) and strontium (none). Other elements which are of significance to ore deposits but which show little variation in the rocks are present in the Miocene rhyolite in the following quantities: gold (0.008 ppm), copper (5 ppm), mercury (0.06 ppm), and chlorine (0.04 percent).

*Gold Acres mine, Nevada.*—T. J. Armbrustmacher found anomalously high concentrations of several metals in rocks from the Gold Acres open-pit mine, Lander County, north-central Nevada. Titanium, chromium, calcium, and magnesium occur in the host rocks and are not related to mineralization, whereas gold, mercury, arsenic, tungsten, zinc, boron, and manganese were introduced into the rocks by hydrothermal processes. Copper, lead, silver, bismuth, and cadmium have also been introduced but only in minor amounts. Calculations of geochemical coherence (correlation coefficients) indicate a strong association among gold, mercury, arsenic, boron, and probably tungsten, and among zinc, copper, and silver. Iron occurs with both suites of metals. These data, together

with data on mineralogy, fluid inclusions, and local variations of elements within the mine, suggest the imprint of at least two sequences of mineralization at Gold Acres. These include an epithermal episode of gold mineralization and a mesothermal episode of base metal enrichment.

*Tenmile district, Nevada.*—Gold-quartz-adularia veins occur in phyllitic rocks of the Raspberry Formation (Triassic) near a Tertiary granodiorite intrusive in the Tenmile district near Winnemucca, Humboldt County, Nev. Fluid-inclusion studies by J. T. Nash show that the mineralizing fluids were of very low density, near 0.65 g/cm<sup>3</sup>, the lowest observed to date for this type of deposit. Homogenization temperatures for the gold stage of mineralization range from 270°C to 330°C for eight deposits; a pressure correction of about 15°C should be added to obtain crystallization temperatures. Depression of freezing-point determinations range from -0.2°C to -4.4°C, equivalent to 0.4 to 7.3 wt percent NaCl. Most values for the gold stage are in the range 0.9 to 2.1 wt percent NaCl.

*Copper Canyon district, Nevada.*—Fluid-inclusion studies by J. T. Nash in the Copper Canyon district, Lander County, Nev., revealed a distinct fluid zonation. A dense brine occurs in inclusions in the contact zone near the intrusive, and a low density, moderately saline fluid in those peripheral to the contact. Economic copper values are restricted to the brine environment, whereas precious metal, lead, and zinc values are related to the less saline fluids. In this district, thermal zonation is not as conspicuous as fluid-density zonation.

*Carlin gold deposit, Nevada.*—Graptolites of Devonian age, identified by W. B. N. Berry (University of California, Berkeley) as *Monograptus hercynicus* Perner and *M. praehercynicus* Jaeger<sup>2</sup>, were collected about 200 feet stratigraphically below the top of the ore zone at the Carlin gold mine, Eureka County, Nev., by T. E. Mullens and J. F. Smith. The graptolites represent a zone near the top of the Lower Devonian; therefore some of the ore below the graptolite zone is probably in rocks of Devonian age. Previously the ore at the Carlin mine had been considered to be limited to rocks of Silurian age.

*Bingham mining district, Utah.*—Three major regional geologic controls that exerted strong influence on localization of base and precious metal ore bodies in the Bingham district, Utah, were (1) a regional pattern of structural openings in (2) a favorable host coincident with (3) a hydrothermal source of base-metal elements related to igneous activity in the region. According to E. W. Tooker, ore-localizing faults and breccia zones are preferentially concentrated in the

steep to overturned ruptured limbs of folds formed during compressive deformation of the upper plate of the Midas thrust fault. The folds trend southeastward in a broad arc across the Oquirrh Mountains. Persistent northeast-trending faults initiated by release of tensional forces produced during folding, but along which later movement was also transmitted, provided the main upward access for igneous intrusion and hydrothermal solutions. Favorable carbonate-rock units in the range were the prime site of ore deposition. The Bingham district lies along the trend of the Uinta-Cortez arch, a major east-trending zone of regional uplift and igneous activity in Utah and Nevada that was a source of hydrothermal solutions.<sup>1, 2</sup>

The reconstructed magmatic history at Bingham indicates that a trend toward more silicic igneous rock compositions is accompanied by decreasing K-Ar ages; the trend suggests a sequential derivation of the igneous rocks through fractional crystallization of a monzonitic magma. Replicate K-Ar dates for a hydrothermal biotite from the disseminated copper ore zone by W. J. Moore and M. A. Lanphere indicate a minimum time interval of 0.6 m.y. between emplacement of the composite Bingham stock and subsequent copper mineralization. A depth of cover at the time of emplacement of 3,000 to 8,000 feet is suggested by recent stratigraphic studies by Tooker and by the calculated stability limits of coexisting phlogopite and actinolite in late-stage dike rocks as described by W. J. Moore (p. C61-C69).<sup>3</sup>

*Marysvale area, Utah.*—The greater Marysvale, Utah, area is a major volcanic pile centered on a large but as yet poorly defined caldera, according to A. V. Heyl. The volcanic pile is underlain by Mesozoic limestones that are known to be favorable for silver-lead-zinc manto and podform deposits similar to those at Tintic. All the principal deposits of gold, silver, lead, zinc, and uranium in the area contain anomalous amounts of mercury, selenium, tellurium, and molybdenum, and some active hot-spring sinters along the youngest faults contain anomalous tungsten and manganese. Mercury and selenium appear to be particularly useful trace elements to locate new areas of promise.

#### Rocky Mountain region

*Creede district, Colorado.*—The early silver-rich fine-grained sulfide paragenesis at Creede, Colo., was deciphered by P. M. Bethke and P. B. Barton, Jr., who found that the silver is closely associated with tetrahedrite-tennantite. The origin of a puzzling com-

<sup>1</sup> Tooker, E. W., 1970, Regional control of ore deposits, Bingham mining district, Utah (U.S.A.) [abs.]: Internat. Assoc. on Genesis of Ore Deposits, Tokyo, Japan, August-September 1970. [In press]

<sup>2, 3</sup> See note opposite page A1 for explanation of reference notations.



mon-ore texture has thus far defied complete explanation. This texture may involve the selective replacement of relatively iron-rich sphalerite (1 percent Fe is "iron rich" in this deposit) by very low-iron sphalerite plus chalcopyrite.

*Gunnison gold belt, Colorado.*—Geologic mapping by J. C. Olson and D. C. Hedlund in the northwestern corner of Saguache County and adjacent parts of Gunnison County, Colo., showed that the small gold deposits of the "Gunnison gold belt" are spatially and probably genetically related to a belt of Precambrian metavolcanic rocks. The belt, including related intrusive rocks, is as much as 7 miles wide, and extends from the Lake Fork of the Gunnison River eastward at least to Cochetopa Creek. The metavolcanic rock units range from basaltic to rhyolitic in composition and are made up of lava flows, breccias, tuff, ash flows, and intercalated sediments. This Precambrian greenstone belt is thought to contain the oldest rocks known in the area studied. The related veins and sulfide deposits which have been mined or prospected for gold are also considered to be of Precambrian age and represent a distinctly older period of mineralization than the thorium-bearing veins of the region.

*Silver Cliff area, Colorado.*—Two, and possibly three, volcanic vent centers, heretofore unrecognized, were defined by remapping the Silver Cliff volcanic area, Custer County, Colo., by W. N. Sharp, and a deeply faulted block of layered flows and lakebeds was outlined between two of the vent areas. Shallow silver halide deposits have been mined from this block. With the recognition of specific volcanic vent areas and a subsidence mass at Silver Cliff, further structural analysis based on this concept should define significant targets for deep exploration.

*Hahns Peak area, Colorado.*—Severe hydrothermal alteration of the Hahns Peak porphyry, Routt and Moffat Counties, Colo., produced a rock enriched in silica, potash, alumina, and water, but depleted in iron, magnesium, and calcium, according to Kenneth Segerstrom and E. J. Young. An original rhyodacitic or quartz latitic rock was transformed to a rock which is rhyolitic in composition. Dark biotite of the original rock was bleached to colorless muscovite, plagioclase was altered to sericite or kaolinite, and fluorapatite was altered to variscite and wavellite (associated with ore minerals); titanium freed by the alteration of biotite formed anatase. In addition, silica veinlets, silicified zones, and disseminated pyrite occur throughout the hydrothermally altered rock. The most common ore minerals are disseminated galena and sphalerite, and the less common ones are silver-bearing tetrahedrite and chalcopyrite. Possible ore-grade material occurs in

a large zone about 1,000 feet southeast of the Hahns Peak porphyry.

*Cooke City area, Montana.*—The gold-copper contact-metasomatic deposits at the McLaren and Gulgarry mines, Cooke City area, Park County, Mont., may be genetically related to an intrusion breccia exposed on Fisher Mountain, according to J. E. Elliott. This breccia consists of porphyritic and nonporphyritic silicic alkalic igneous rocks and is probably a late phase of the more extensive monzonite porphyry of Henderson Mountain<sup>4</sup> which it intrudes. A mafic pluton in the Goose Lake area near the Copper King mine that had been earlier called Tertiary gabbro is now believed to be Precambrian metadiabase similar to dikes and plutons to the southeast in the Beartooth Precambrian terrane.

*Virginia City area, Montana.*—A diatreme is exposed at or close to the contact between Precambrian gneiss and Tertiary volcanic rocks in a recently reopened old adit of the U. S. Grant Mine in Alder Gulch near Virginia City, Madison County, Mont. K. L. Wier reported that the diatreme fill is extensively altered and consists mainly of basaltic material and sparse gneiss fragments. The diatreme extends beyond the area of the adit, but its limits have not yet been determined. Nearby exploration drilling reportedly ended at a depth of 500 feet in "decomposed basalt" that probably represents diatreme fill.

#### Midcontinent and Eastern United States

*White Pine copper deposit, Michigan.*—Calculations by W. S. White on the basis of grain-size studies of the Nonesuch Shale and Freda Sandstone in Ontonagon and Gogebic Counties, Mich., indicate that these rocks would probably have been sufficiently permeable for millions of years after deposition to permit vertical passage of enough copper-bearing solution to form the White Pine deposit. Mineralization by diffusion seems less likely because of the difficulty of maintaining an adequate copper concentration in the interstitial water of the underlying formation over the large area involved.

*Central Tennessee zinc district.*—The mineralogy, sequence of deposition, and trace-element content of sphalerite, barite, fluorite, calcite, and galena in the central Tennessee district were found by A. V. Heyl and J. L. Jolly to be remarkably similar to those in the central Kentucky district, but largely dissimilar to the Mascot, Flat Gap, and Powell River belts in eastern Tennessee. Principal minerals in the central Tennessee deposits are two-color (yellow and black), red, or red-orange sphalerite, and galena, fluorite,

<sup>4</sup>Lovering, T. S., 1930, The New World or Cooke City mining district, Park County, Montana: U.S. Geol. Survey Bull. 811-A, p. 1-87.

barite, calcite, and drusy quartz that fill fissures and cement breccias in rocks of Early Ordovician to Mississippian age. Replacements of wallrocks are almost unknown except for jasperoid and clay minerals, and ore-stage dolomite is not abundant. In contrast, the eastern Tennessee deposits are mainly replacement bodies of yellow sphalerite, dolomite, and calcite, very locally containing galena. In central Tennessee and central Kentucky all sphalerites contain notable quantities of germanium, gallium, copper, and detectable manganese; the earlier deposited sphalerites contain as much as 300 ppm Hg, and the later ones, less than 1 ppm Hg. Eastern Tennessee sphalerites contain less germanium, gallium, copper, and manganese, and none analyzed to date contain more than 5 ppm Hg; all contain detectable silver. Most central Tennessee and central Kentucky barites are strontium-rich, whereas eastern Tennessee barites contain only 2 percent Sr or less, and galenas are notably radiogenic compared to those in eastern Tennessee.

*East Tennessee zinc district.*—A sheared and sinuously contorted veinlet of sphalerite from the Felkner prospect, Jefferson County, Tenn., suggests that the veinlet was crushed during postmineralization compaction of the enclosing fine-grained dolomite. Detailed measurement of the contorted veinlet boundaries by Helmuth Wedow, Jr., shows that, if this interpretation is correct, the thickness of the fine-grained dolomite was reduced by 26.5 percent after the emplacement of the veinlet. This amount of postmineralization compaction is about the same as that of the postbrecciation thinning reported previously<sup>5</sup> (U.S. Geological Survey, r0424, p. A9)<sup>6</sup> for marker beds at the Flat Gap mine in Hancock County, Tenn., and is further indication that the east Tennessee deposits formed at relatively shallow depth.

*Gardner Mountain area, New Hampshire.*—J. P. D'Agostino found that the sulfide deposits of Gardner Mountain and the lower Ammonoosuc Valley, Grafton County, N.H., were originally formed parallel to the bedding during the Middle Devonian by mineralized solutions permeating the porous beds of sedimentary strata ranging in age from the Albee Formation (Middle Ordovician) to the Littleton Formation (Lower Devonian). The ore-bearing solutions were probably genetically related to the mafic sills and granitic intrusives of Middle Devonian age. The sulfide ore occurrences and the accompanying sedimentary strata were severely brecciated, sheared, and foliated by intense regional folding during the Late Devonian

Acadian orogeny. Low-grade regional metamorphism after the folding resulted in the solution and movement of sulfides and silica that formed mineralized sheet quartz veins parallel to the schistosity and filled tension fractures that cut the schistosity. The quartz-filled tension fractures, although lean in sulfides and limited in extent, are richer in gold than other occurrences in the area.

## FERROUS METALS

*Gogebic iron range, Michigan.*—The rocks in the central part of the Gogebic iron range from Ironwood to Ramsay, Gogebic County, Mich., may have been metamorphosed to only a very low grade, if at all. Ground magnetic traverses across the central part of the range indicate that most of the iron-formation is only slightly more magnetic than underlying quartzite, siltstone, and granite, and is much less magnetic than parts of the overlying Tyler Slate. Although magnetite is generally thought to have been the main oxide in unaltered and unmetamorphosed iron-formation over the whole Gogebic range, it is sparse in the central part of the range, and R. G. Schmidt postulates that its sparsity is related to the primary mineral suite instead of to secondary alteration or metamorphism. Likewise, minnesotaite and stilpnomelane are scarce in the central part of the range, although they are common in the higher-grade areas both east and west. The chert of the central area is very fine grained. Chlorite-type silicates occur widely but in small amounts, and on the basis of X-ray analyses, J. W. Hosterman concluded that some of these are chamosite. In the unaltered rock most of the iron is in siderite, but primary hematite is also common. Minute structures of probable organic origin are well preserved. Coaly material (metaanthracite?) in the overlying Tyler Slate is metamorphosed, but it is less crystalline than graphite. If minnesotaite and stilpnomelane are indeed absent from the least metamorphosed part of the formation, this may help to show that, where present, these are true metamorphic minerals.

*Iron at Black River Falls, Wis.*—Harry Klemic, in cooperation with the Jackson County Iron Mining Co. (a subsidiary of Inland Steel Co.), has been studying the newly developed iron deposit and surrounding area at Black River Falls, Jackson County, Wis. Magnetic taconite iron-ore bodies occur in discontinuous zones in steeply dipping Precambrian iron-formation that crops out locally and that extends beneath a cover of sandstone of Late Cambrian age. The iron-formation and adjoining metasedimentary rocks have been intruded by diabase dikes and by granite. Magnetite is the predominant iron mineral in the ore bodies,

<sup>5</sup> Hill, W. T., and Wedow, Helmuth, Jr., 1969, Porosity and permeability of Lower Ordovician carbonate rocks in East Tennessee during early Middle Ordovician time [abs.]: *Econ. Geology*, v. 64, p. 350-351.

<sup>6</sup> See note opposite page A1 for explanation of reference notations.

but specularite, martite, and red hematite are abundant in some zones. Goethite occurs in only minor amounts, mainly in weathered surficial parts of the iron-formation. Although the intensity of metamorphism of some of the iron-formation has resulted in the crystallization of biotite, hornblende, garnet, and other silicate minerals, the iron oxide minerals have remained relatively fine grained. Pyrite, chalcopyrite, and other unidentified sulfides occur in minor amounts in some of the formations, particularly in and near the diabase intrusives. A rubble of fragments of iron-formation cemented by quartz sand occurs in a thin zone at the base of the Cambrian sandstone in the vicinity of some knobs of iron-formation that have been exposed by erosion of the overlying sandstone.

*Strawberry tungsten mine, California.*—The Strawberry tungsten mine area, located in the southeast corner of the Merced Peak quadrangle, Madera County, Calif., is composed of a small roof pendant of meta-sedimentary rocks and metamorphosed shallow intrusives that are surrounded by Mesozoic granitic intrusives. Planetable geologic mapping and structural analysis of minor folds by W. J. Nokleberg indicate that the wallrocks underwent four periods of deformation before intrusion of granitic magmas. The periods of deformation appear to have formed a regional pattern of superimposed folds that can be traced to other roof pendants in the central Sierra Nevada. A geochemical study of the tungsten deposits indicates that marble beds in the pendant are metasomatized to andradite-hedenbergite-scheelite-tactite. Metasomatism probably occurred when volatile-rich fluids, which concentrated silicon, iron, and tungsten, were expelled from a granodiorite magma. The various contact-metasomatic assemblages and their oxidation states can be explained by a simple model that considers the interaction of the ore-forming solutions with large amounts of CO<sub>2</sub> during replacement of the marble.

#### GEOCHEMICAL HALOS AND ANOMALIES

*Skull Creek anticline, Colorado.*—R. A. Cadigan detected a metal-rich geochemical halo at the contact of the green siltstone facies with the overlying red siltstone facies within the Moenkopi Formation (Triassic) on the flanks of the Skull Creek anticline, Moffat County, Colo. The halo persists fairly continuously along more than 25 miles of outcrop in the erosional scarp which concentrically borders the oblate anticlinal dome. Copper in the halo ranges from 100 ppm disseminated in clayey siltstone to several tens of percent in malachite seams 1 mm thick. Other metals present in the halo in anomalous amounts are silver, lead, zinc, uranium, and arsenic. Along the southern scarp,

mercury values in the green facies range from 0.1 ppm to greater than 10.0 ppm—highly characteristic of hydrothermal mineral deposits. The presence of the halo, the mercury values in the green facies, and other anomalous metal occurrences in the anticline area, including a small mined-out uranium deposit, suggest that the green strata of the Moenkopi have undergone large-scale hydrothermal alteration of regional significance.

*Molybdenum with fluor spar, Northgate, Colo.*—Anomalous amounts of molybdenum occur in Precambrian wallrocks surrounding a banded fluorite vein at Northgate, Jackson County, Colo. At the surface, R. G. Worl found as much as 150 ppm Mo in apparently unaltered rock within a zone about 100 feet wide that centers on the vein. Wallrock is not altered at the surface except for minor silicification and pyritization along the contact. On the 400- and 500-foot levels of the fluor spar mine, as much as 80 percent of the wallrock is altered to as far as 70 feet from the vein, the limit of mine workings. Altered parts of wallrock contain as much as 800 ppm Mo, and the amount decreases away from the vein. The alteration is reflected mainly by a color change of the parent pink Precambrian quartz monzonite to a dark-gray veined rock, and by a loss of magnetite, the introduction of pyrite, minor alteration of biotite to chlorite, and the introduction of a stockwork of veinlets. These dark-gray veinlets are pervasive through the rock, even along mineral cleavage planes, and are composed of a fine mixture or intergrowth of fluorite, chalcedonic quartz, pyrite, and in one place, molybdenite. This material resembles in color and composition the black fluorite, chalcedony, and pyrite that make up the bulk of the fluor spar vein in the lower levels of the mine. Possible Tertiary intrusive material from the vein zone also contains anomalous amounts of molybdenite, up to 500 ppm.

*Zinc in North Gouverneur area, New York.*—A thin replacement vein of sphalerite was located by C. E. Brown (p. D162–D168) in a sequence of Precambrian dolomitic marble about a mile west of North Gouverneur in the Richville quadrangle, St. Lawrence County, N.Y. Fifty soil samples taken from a 300- by 1,000-foot grid define a zinc anomaly aligned with the trend of the vein which is also parallel to the layering in the marble. Mercury shows a similar, but greatly accentuated anomaly. This occurrence is about 15 miles from Balmat, N.Y., where large ore bodies of sphalerite are being mined.

*Tin in Mount Rehovah area, South Carolina.*—Several samples of sediment from small streams in the Mount Rehovah area, Fairfield and Richland Counties, S.C., taken by Henry Bell III, have heavy-mineral con-

centrates that contain more than 1,000 ppm Sn, and two contain 1 or 2 percent. Bedrock containing such large amounts of tin is not known in the area, and these high values may result from concentration of a tin-bearing mineral derived from conglomerates in basal Coastal Plain sedimentary rocks which are present on some stream divides.

### PLACER DEPOSITS

*Tertiary gravels, California.*—Analyses of approximately 150 gold-bearing samples from three churn drill holes in Tertiary stream gravels in the North Columbia pit, Nevada County, Calif., showed an average of \$0.013 to \$0.07 gold per cu yd in the upper parts of the holes and \$0.49 to \$0.668 in the lower parts. These values are generally lower than those obtained from earlier drilling done by private interests. Most gold in the lower "rich" zones occurs as flakes 1 to 2 mm in diameter and 0.1 to 0.2 mm in thickness; the largest was 3.0 mm in diameter. Generally the flakes are shiny, rough, and show scattered coatings of iron oxide and (or) silica. All flakes are flattened, have rounded outlines, and are generally abraded. Gold fragments coarser than 1 mm in diameter were not seen more than 80 feet above bedrock in the holes.

Seismic work using the delay-time method, carried out by H. W. Oliver between North Bloomfield and San Juan Ridge in Nevada County, Calif., indicated that this method is feasible to define bedrock configuration beneath less than 600 feet of volcanic cover to an accuracy of about 50 feet. This degree of precision is adequate to outline the 100- to 300-foot-deep channels of the Tertiary Yuba River which commonly contain auriferous gravels. As a byproduct of the study a previously undetected channel in the bedrock was found extending northeasterly from the Malakoff diggings and crossing under Humbug Creek about 1½ miles north of North Bloomfield.

*Northwest Wyoming conglomerates.*—The occurrence of gold of detrital origin in the quartzite conglomerates of northwest Wyoming was confirmed by J. C. Antweiler and W. L. Campbell through study of gold grains obtained by hydrofluoric acid decomposition of quartzite cobbles. Thin, flat flakes of gold had silver-deficient rims—a feature characteristic of detrital gold. Gold of primary origin in the conglomerates was also confirmed in quartzite cobbles that contained sulfides, notably pyrite and chalcopyrite, and that yielded small spherical gold particles whose outer shell had the same composition as the center. Microscopic examination of gold particles in the conglomerates from many localities together with compositional studies by electron microprobe and spectrographic methods indicate at least two and perhaps four source areas for the gold.

*Source of placers in Iron Springs Divide area, Colorado.*—P. K. Theobald determined that the placer deposits flanking Iron Springs Divide, Moffat County, Colo., have a local source in arkose lenses of an Eocene deltaic fan. The base and northern limit of these lenses are well defined in north-facing bluffs south of the Little Snake River, thus defining the northern limit of possible placers derived from this source.

*Black sandstones, Rocky Mountain region.*—Two major regional heavy-mineral provinces, volcanic and nonvolcanic, were defined by R. S. Houston through study of fossil black sandstone of Late Cretaceous age in the Rocky Mountain region. The volcanic province includes all of Montana and parts of Wyoming and is marked by a dominance of titaniferous magnetite, intergrown iron-titanium oxides such as ulvospinel-magnetite, and minor chromite and ilmenite in the opaque mineral suite. Oxyhornblende, pyroxene, sphene, apatite, euhedral biotite, and euhedral zircon are especially abundant and are probably of volcanic origin. Several lead-alpha dates on the euhedral zircons from Wyoming yield Cretaceous ages (same age as the rocks they are in) and support the concept that they are volcanic in origin. Rock fragments of volcanic origin are also common in many of these deposits. Black sandstones in the nonvolcanic province contain heavy minerals such as ilmenite, zircon, monazite, rutile, tourmaline, epidote, and garnet that were probably derived from sedimentary rocks. Most of these minerals are very well rounded, suggesting multicycle deposition. These mineral suites are more common in Colorado, Utah, New Mexico, and Arizona.

Fossil black sandstones of the Rocky Mountain region represent a resource of well over 50 million tons of iron-titanium oxides and zircon, with monazite, chromite, rutile, niobium-bearing opaque minerals, and gold as possible byproducts. The deposits are probably not of economic value today, because in the north the magnetite contains too much titanium for iron ore and in the south the ilmenite is generally so highly altered that it is difficult to process. Locally the deposits have been mined as a source of heavy aggregate and as a source of iron in cement manufacture.

*Composition of placer gold in Colorado mineral belt.*—Investigation of more than 1,000 placer gold grains collected from 17 localities in the northeastern part of the Colorado mineral belt from the Boulder district to the Alma-Fairplay district shows that, for many of the occurrences, the silver and (or) copper content of the core alloy can be related to the parent lode deposit or district. Allowing for the effect of the low-silver rim of placer grains on bulk assays, G. A. Desborough, W. H. Raymond, and P. J. Iagmin found

good agreement between results of microprobe analysis of a small number of grains with that of gold fineness as determined by commercial assays and mine production data.

*Gold-bearing gravels, South Dakota, Wyoming, and Nebraska.*—H. A. Tourtelot, R. F. Gantnier, and E. B. Ternes found gold in amounts ranging from 0.2 to 19.0 ppb in 48 of 140 samples of rocks of Oligocene, Miocene, and Pliocene age and of terrace gravels of Quaternary age east of the Black Hills and the Rocky Mountain front in South Dakota, Wyoming, and Nebraska. These values were calculated from analyses of heavy concentrates of separate size fractions for each sample; the gold contents of the concentrates themselves ranged from 1 to 100 ppm. The gold occurs as flakes chiefly in the  $61\mu$ -to- $88\mu$  and  $40\mu$ -to- $61\mu$  fractions, and the amounts of gold show no relation to grain size, sorting, or other parameters of the samples, which ranged from siltstone to conglomerate and gravel, or to the amount of heavy minerals in either the total sample or individual size fractions. The geographic distribution of gold-bearing samples suggests three temporally and spatially distinct source areas: (1) the Laramie Mountains west of Cheyenne, Wyo., in late Miocene and Pliocene time; (2) the northern part of the Hartville uplift and (or) north end of the Laramie Mountains farther to the west in Oligocene and Miocene time; and (3) the northern part of the Black Hills in Oligocene, late Pleistocene, and Holocene time.

#### BEHAVIOR OF GOLD IN WEATHERING

*Southern California.*—Z. S. Altschuler found that the gold content of soils developed on igneous rocks of southern California is not significantly different from that of the parent materials. There is, however, a transitory concentration of gold in the iron coronas of spheroidal boulders during incipient stages of weathering. Subsequent soil development effects a dispersal of such enriched phases throughout the profile, and the net enrichment in gold is low.

*Southeastern United States.*—A study of semiquantitative data on samples of saprolite and fresh mica schist from the Calhoun mine, Lumpkin County, Ga., by F. G. Lesure indicates that several minor elements, including gold, have been enriched in the saprolite about  $1\frac{1}{4}$  to 2 times the concentration in the fresh rock. The specific gravity of the unweathered schist ranges from 2.7 to 2.9 and of the saprolite from 1.5 to 1.9. This suggests that one-third to nearly half of the original material has been removed during weathering. Although no gold was detected in 17 samples of fresh schist, pyrite separated from fresh schist off the dump

of the adit contains 0.2 ppm Au. Inasmuch as some zones in the fresh schist contain 0.5 to 1 percent pyrite, the gold content of the fresh rock should be about 0.01 to 0.02 ppm, which is below or just at the limit of detection. In contrast, 11 out of 12 samples of saprolite contain 0.02 to 0.1 ppm Au. The removal of 40 percent of the soluble material from the fresh schist would produce the gold concentration inferred in the saprolite.

Many lateritic soils and saprolites in the southeastern gold belt are abnormally rich in gold. Differential solution of the iron oxide phase of laterite collected near gold mines does not reveal any concentration of soluble or fine colloidal gold, and Z. S. Altschuler postulates that enrichment in the laterite is due to very fine particulate gold of alluvial or colluvial origin. In contrast, iron concretions on soils immediately overlying gold mines are enriched in ionic or fine colloidal gold.

#### LIGHT METALS AND INDUSTRIAL MINERALS

##### Underclay of Pennsylvania

Studies of the chemical composition of underclays associated with the anthracite beds in eastern Pennsylvania by J. W. Hosterman (p. C89-C97) show that they are similar to the plastic underclays of the bituminous coal fields. However, the mineralogy of the two kinds of underclay is very different. The underclays of the bituminous coal contain kaolinite and illite ( $Md$ ) and occasionally diaspore. The underclays of the anthracite beds contain kaolinite, illite ( $2M$ ), chlorite, pyrophyllite, and phlogopite; quartz is the only nonclay mineral. This clay mineral assemblage indicates that anthracite formed in the greenschist range of temperature ( $250^{\circ}$  to  $450^{\circ}\text{C}$ ) and pressure (2,000 to 9,000 bars).

##### Peat

Reserves of commercial quality peat are estimated by C. C. Cameron (p. D153-D161) as 630,000 short tons in the mountains of West Virginia and Maryland, with largest deposits in Canaan Valley, Tucker County, W. Va. Peat occurrences in the Appalachian Mountains south of the glacial border are restricted to swamp deposits in structurally controlled basins at high altitudes; potentially exploitable peat resources are further restricted to deposits in basins on low terraces and interfluvies representing old gradational surfaces trenched by modern streams, and thus isolated from diluting effects of stream sediment.

Peat deposits in swamps in St. Lawrence County, N. Y., accumulated in depressions in glacial drift and in bedrock valleys dammed by glacial debris. Field observation shows that deposits with the highest commercial potential both in quality and quantity are re-

stricted to sites of partly buried preglacial valleys along contacts of marble with gneiss or schist in the Grenville Series (Precambrian).

### **Beryllium**

Large deposits of fluorite that contain beryllium minerals, found by C. L. Sainsbury during an investigation of the tin deposits of the Lost River area, Alaska, are again under active exploration by private industry. PCE Explorations, Ltd., of Toronto, Canada, has staked all open ground in the beryllium district and has completed an option to purchase the Lost River tin mine area, which includes the largest beryllium-fluorite deposit at Camp Creek. A full-scale metallurgical testing program of the complex beryllium-fluorite ore is under way at Battelle Institute, Columbus, Ohio, and extensive diamond drilling is planned for 1970.

### **Mineralogy of marine phosphorite deposits**

X-ray and chemical studies by J. B. Cathcart on phosphate samples from different areas and from different geologic ages show that the phosphate mineral of all marine phosphorites is a carbonate fluorapatite, but that the mineral varies toward the fluorapatite end of the series in geologically old rocks—that is, the apatite with the highest CO<sub>2</sub> content is in the Miocene of North Carolina and Sechura, Peru, whereas the one closest to fluorapatite (least CO<sub>2</sub>) is the rock from the upper Precambrian of Brazil. Metamorphosed marine phosphorites are fluorapatites—all CO<sub>2</sub> has been driven off. Laboratory work indicates CO<sub>2</sub> is driven off by heating to about 800°C for as little as half an hour.

### **Dawsonite**

Dawsonite, a basic carbonate mineral, is a potential source of aluminum and byproduct sodium, but recent studies show that great care should be made in the use of X-ray peak intensities to estimate dawsonite content in shale samples for resource calculations.

Systematic measurement by E-an Zen of X-ray peak intensities for two peaks of dawsonite, chosen for their strength and their freedom from interference by other peaks, against an internal standard of quartz showed that the dawsonite peaks are sensitively affected by the length of grinding. In two series of tests, grinding of the quartz-dawsonite mixture ranged from 5 to 30 minutes, and the peak intensities of dawsonite decreased by as much as 100 percent, the precise figure depending on the peak, the original crystallinity of the sample, and the method of intensity measurement (total area versus peak height).

### **Sulfur**

Within the New Mexico segment of the Delaware basin, according to J. S. Hinds and R. R. Cunningham,

shows of sulfur are found from the surface to depths of 15,000 feet. Most occur in dolomite of the San Andres, Abo, and Yeso Formations and in limestones of the Artesia Group; surface shows of sulfur also are known in the Castile Gypsum.

Large deposits of sulfur have been found in equivalent stratigraphic units to the south in Culbertson and Pecos Counties, Tex., each lying in cavernous brecciated carbonate masses; comparable limestone masses also crop out in Eddy County, N. Mex. Although sulfur deposits of commercial size have not been found north of the Texas border, the widespread existence of the mineral and the similarity of host rocks indicate that the New Mexico area also is a favorable one for sulfur exploration.

### **Titanium**

*Roseland district, Virginia.*—Panned stream concentrates from the Roseland district, Nelson and Amherst Counties, Va., were collected by Norman Herz and W. C. Overstreet and later analyzed by L. B. Valentine and E. R. Iberall for rutile, zircon, ilmenite, and magnetite. Rutile was found to be concentrated in the +40 screen size where it averaged 11.4 and 8.8 percent, respectively, in the Tye and Piney River drainage areas. Ilmenite was abundant in all samples, zircon was largely concentrated in the +200 screen size, and magnetite was present in generally sparse amounts. The results indicate a good possibility that valuable placer deposits of titanium minerals may be present, as reported by Herz, Valentine, and Iberall (r0422).<sup>7</sup>

*Harford County area, Maryland.*—Norman Herz and F. G. Lesure collected hard-rock and panned stream-concentrated samples from the Harford County, Md., serpentinite belt. Rutile was already known to occur in the belt at the Dinning prospect where pockets contain up to 16 percent rutile. Analysis of the samples by L. B. Valentine and C. N. Mayhew indicated that the probable tenor of rutile in most of the serpentinite is 1 percent or less. Magnetite is, however, abundant throughout the serpentinite, reaching a maximum of 90 percent in one panned heavy-mineral concentrate. The serpentinite can be considered a potential economic source for both rutile and magnetite (p. C43–C48).

## **RADIOACTIVE MATERIALS**

### **URANIUM**

**Tritium concentration key to flow rate of uraniferous ground water in Black Hills, S. Dak.**

C. G. Bowles reported that tritium content of uraniferous ground waters in the Inyan Kara Group (Lower Cretaceous) in the Edgemont district, southern Black

<sup>7</sup> See note opposite page A1 for explanation of reference notations.

Hills, S. Dak., reveals their flow rate. Tritium concentrations (analyses by J. D. Larson and L. L. Thatcher) range from 14 ( $\pm 20$ ) T.U. to 313 T.U. The higher concentrations probably are related to surface waters entering the Inyan Kara during peak atmospheric tritium concentrations of 1963, and their position relative to recharge points suggests that in places ground water in the Inyan Kara rocks flows at least 15 f.p.d. At this rate water containing less than 20 ppb U could be an effective mineralizing solution.

#### **Tertiary stratigraphy and uranium-deposit controls in Wyoming**

Regional geologic mapping and detailed petrographic work by N. M. Denson (r0108, r0285) help establish Tertiary stratigraphy and uranium-deposit controls in Wyoming. Six major subdivisions of the Tertiary (Paleocene, lower Eocene, upper Eocene, Oligocene, lower Miocene, and upper Miocene and Pliocene) are found from the southern terminus of the Wind River Mountains through central Wyoming into northwestern Nebraska. The ages of these subdivisions have been established by the faunal and floral succession and are supported at many localities by potassium-argon age determinations of the associated tuff.

Petrographic work on 3,000 heavy-mineral separates from the six major lithogenetic units (Fort Union, Wasatch, Bridger, White River, Arikaree, and Ogallala Formations) from 250 stratigraphic sections reveals that each subdivision has a distinctive heavy-mineral assemblage which substantially aids correlation. These mineral assemblages also help in establishing the major tectonic events affecting the region during the Tertiary.

Widespread volcanic activity in and adjacent to the middle Rocky Mountains began in late Eocene time and is clearly reflected by abundant heavy minerals of volcanic origin over thousands of square miles, contained in an impervious, highly bentonitic sequence of rocks. These rocks were locally removed by pre-Oligocene erosion, and such places are thought to be most favorable for occurrence of uranium deposits in underlying rocks.

#### **Fault control of uranium deposits at Badwater Creek, Wyo.**

Geologic mapping of the Tertiary sequence in the Badwater Creek, central Wyoming, uranium area by R. E. Thaden indicates zones of subparallel faults, downthrown basinward, separated by relatively unfaulted ground. Existing hydrostatic gradients indicate that ground-water flow is deflected along the fault zones; hence uranium deposits precipitated from the ground waters are expected to be in linear rows on the upgradient side of the zones. They are likely to be

narrower and smaller than deposits known elsewhere in Wyoming Tertiary basins.

#### **Equilibrium-disequilibrium in uranium ore bodies, Gas Hills, Wyo.**

Some equilibrium-disequilibrium characteristics of uranium ore bodies in the Gas Hills of central Wyoming have been long known, according to F. C. Armstrong. A centrally located zone in each crescent-shaped ore body is in radioactive equilibrium. On the convex side the  $\beta/\gamma$  ratio increases (high- $\beta$  ore) progressively away from the zone in equilibrium, and on the concave side the  $\beta/\gamma$  ratio decreases (high- $\gamma$  ore) progressively away from the zone.

Recognition of this equilibrium-disequilibrium condition is important for economic reasons in exploration and mining and has significant scientific implications.

The equilibrium-disequilibrium pattern indicates that uranium in the zone in radioactive equilibrium was deposited at least about a million years ago, and further, that dates based on radioactive decay are not reliable. The pattern also indicates that uranium and its daughter products have been and (or) are being preferentially leached and transported within each ore body. Moreover, the pattern may indicate a genetic model for the ore bodies in which the transport and deposition of the uranium can be accounted for by the chemical characteristics of present-day ground water.

#### **Recoverable $U_3O_8$ in the Gas Hills district, Wyoming**

F. C. Armstrong estimated possible ultimate uranium production from the Gas Hills district, Wyoming, on the basis of present knowledge of the geology and past production of the district. The district has yielded about  $5 \times 10^7$  lb  $U_3O_8$  through 1969. Ultimate production probably will exceed  $10 \times 10^7$  lb  $U_3O_8$  and may reach  $15 \times 10^7$  lb, assuming a stable price of \$8 per lb. Increase in price within the next few years to \$10 to \$12 per lb could increase yield to  $17.5 \times 10^7$  lb  $U_3O_8$ . If the price of  $U_3O_8$  ever reaches \$25 per lb (in 1969 dollars), it would be feasible to mine by open pit some of the deep, thin, low-grade mineralized material found on the extended lower "horn" of crescent-shaped ore bodies, and thus the district might yield a maximum of  $20 \times 10^7$  lb  $U_3O_8$ .

#### **Similarities and differences among sandstone-type uranium deposits**

The similarities and differences of the Wyoming roll-type uranium deposits and the Colorado Plateau peneconcordant type focus attention on some unresolved genetic problems—the Eh of the ore-bearing and altering solutions, the shape and localization of the deposits, and the source of uranium. According to R. P. Fischer the Wyoming deposits are elongate cres-



cent-shaped bodies that extend vertically through or partly through a sandstone unit, and are scattered, like widely spaced beads on a string, along miles-long interfaces between oxidized (altered) and unoxidized sandstone; whereas the Plateau deposits are thin tabular layers nearly concordant to bedding, and occur as discrete bodies, like raisins in raisin bread, engulfed in rock altered by reduction. The Wyoming ore rolls and interfaces are generally thought to have been dynamic, having been pushed down dip by downward moving oxygen-bearing water that passed through the interfaces and deposited the ore minerals on the reducing side; whereas the Plateau deposits seemingly formed as static bodies, localized by intensive reducing "patches" in a mildly reducing environment. The host rocks in the Wyoming and Plateau deposits (and also in the somewhat similar deposits in Texas and the Black Hills) differ some in lithologic characteristics and source areas, but the deposits in all four areas are associated with beds containing volcanic debris.

#### **Uranium resources in northwestern New Mexico**

The occurrence and geologic setting of an estimated 200 million tons of uranium resources expected to average 0.25 percent  $U_3O_8$  in northwestern New Mexico has been presented in a comprehensive report by L. S. Hilpert (r0243).

#### **Potential uranium area in the southern High Plains**

Generalized stratigraphic columns prepared by W. I. Finch for the southern High Plains of southeastern Colorado, eastern New Mexico, and western Texas indicate that post-Triassic sedimentation was markedly more continuous in the northern part than in the southern part. Flow of ground water through the Triassic was affected differently in the two parts during the Cretaceous and Tertiary. In the southern part connate water was flushed out by recharging ground waters during long intervals of exposure and erosion of Triassic rocks; in the northern part flow of connate and meteoric ground water was slowed until breaching in the Quaternary. Thus the northern part of the region probably is more favorable for finding uranium deposits than the southern part, and the Raton basin is particularly favorable.

#### **Similarities of south Texas coastal plain and Wyoming uranium deposits**

E. N. Harshman reports that analyses of samples of altered sandstone, ore, and unaltered sandstone from roll-type uranium deposits in the south Texas coastal plain show a distribution of elements similar to the Wyoming deposits. This and other similarities, such as the spatial relation of the deposits to tongues of

altered sandstone, the alkaline environments in which the deposits are found, and the close association of the deposits with tuffaceous rocks, suggest that the coastal plain and the Wyoming deposits were formed by geochemical processes that were much alike, and that exploration guides developed in Wyoming may prove applicable in Texas.

#### **Paleostream courses may have localized uranium in south Texas**

According to D. H. Eargle, paleostream channels in south Texas, believed to be former courses of the Rio Grande and the Nueces River, contain boulders tentatively identified as of types found in western Texas about 400 miles to the northwest. Pebbles and boulders in Miocene to Pleistocene rocks in Duval County can be related to specific stocks or flows, or to beds of welded tuff in the Big Bend. A boulder containing Permian fusulines must have originated in the Glass Mountains area of the Trans-Pecos region.

The presumed Pleistocene course of the Rio Grande can be traced about a hundred miles north of its present valley, across the Bordas Plain to Baffin Bay, a tributary of Laguna Madre of the Gulf of Mexico. This channel and that of the Nueces are currently being explored for uranium.

#### **Uranium-rich monazites in the Inner Piedmont, North and South Carolina**

W. C. Overstreet, A. M. White, and J. J. Warr, Jr. (p. D169-D175), report that the most uranium-rich monazites in the United States occur in the western monazite belt in the Inner Piedmont, North and South Carolina. These monazites contain 0.95 percent or more  $U_3O_8$ , and represent the upper 5 percent in  $U_3O_8$  content of 283 samples of monazite from the United States. The principal sources of the detrital monazites analyzed in this study are granitic rocks and pegmatites ranging in age from Ordovician to Permian. A post-tectonic quartz monzonite, Mississippian (?) to Permian (?) in age, yields monazite that contains the most  $U_3O_8$  (2.34 percent) yet reported from the United States.

### **THORIUM**

#### **Thorium-bearing veins and copper-bearing veins in Lemhi Pass quadrangle, Idaho**

Thorium-bearing veins and copper-bearing veins in the Lemhi Pass quadrangle, Idaho and Montana, make up two distinctive groups, according to M. H. Staatz. The thorium-bearing veins have two principal orientations, N. 40°-50° W., and N. 70°-80° W. The copper-bearing veins have many orientations, but at least half strike northeasterly. The fractures that the veins oc-



cupy evidently were formed in the Tertiary, probably at the same time that major faults were developed. The veins formed after deposition of the Challis Volcanics.

## ORGANIC FUELS

### Coal-mine roof falls related to lithology of overlying beds

Geologic mapping in Greene County, Pa., by B. H. Kent, has shown that the frequency of roof falls in mine workings of the Pittsburgh coal bed is related to the areal distribution of the "Pittsburgh" sandstone which locally overlies the coal bed. Mine roof failures are most common where the coal is overlain by deformed shale, in zones about 500 feet wide marginal to the thick lenticular sandstone bodies. The intense deformation of the rocks in these marginal zones probably results from differential compaction. The shale in the marginal zones is also subjected to concentrated stresses, caused by overburden pressure, surrounding the more rigid lenses of sandstone. Differential compaction, combined with concentrations of stress, are primary causes of roof-rock failure.

### Low-sulfur and low-volatile coal resources in West Virginia

The amount of recoverable coal containing less than 1 percent S in 11 counties in West Virginia is estimated by K. J. Englund, D. G. Hadley, and F. D. Spencer to be approximately 8.5 billion tons. In part of the coal-field area, northeast of the Cumberland overthrust sheet, geologic conditions are favorable for the occurrence of low-volatile coal at depth.

### Oil shale in the Piceance Creek area, Colorado

Three rich oil-shale zones in the Piceance Creek basin have been estimated by J. R. Donnell to contain 300 billion bbl of shale oil. In an area of about 75 sq mi on the western margin of the basin one of these zones, the Mahogany ledge, contains approximately 8 billion bbl of oil under less than 400 feet of overburden.

### Oil-shale stratigraphy

In the Barcus Creek SE quadrangle, Colorado, W. J. Hail, Jr., observed a complex intertonguing relationship between the oil-shale-rich Parachute Creek Member and the overlying Evacuation Creek Member of the Green River Formation. Sandstone and siltstone units in the lower part of the Evacuation Creek thin to the southeast, where they are interbedded with marlstone of the Parachute Creek Member. The boundary between the two members may be as much as 650 feet lower stratigraphically at the mouth of Yellow Creek than at the mouth of Piceance Creek, 9 miles to the southeast. Farther east in the Powell Park area, Colo-

rado, a 10-foot-thick interval of dolomitic concretions near the top of the Douglas Creek Member of the Green River Formation was traced for several miles by G. N. Pipiringos. This zone may be a useful stratigraphic marker in adjoining areas.

### Increased oil reserves in the Elk Hills field, Naval Petroleum Reserve No.1, California

Previously uncounted oil reserves have been reported in several Pliocene sands in the western portion of the Elk Hills oil field according to J. C. Maher, R. J. Lantz, and R. D. Carter. Calculations, based on the limited data presently available, indicate as much as 100 million bbl of additional oil is contained in relatively subtle stratigraphic traps related to unconformities and facies changes as well as more obvious traps formed by the anticlinal structure.

### Importance of Mississippian rocks in the production of oil and gas from the northern Appalachians

Comparison by L. C. Craig and others of a map showing the distribution of oil and gas fields producing from Mississippian rocks, specially prepared by Wallace de Witt, Jr., with a previously published<sup>8</sup> map showing all oil and gas fields reveals that more than one-third of the producing area of the northern Appalachians is in Mississippian rocks. The Mississippian System is therefore indicated to be an important source for oil and gas in the Appalachian region.

### Unusual fault traps for natural gas north of the Bearpaw Mountains, Mont.

The recently discovered gas underlying nearly 200 sq mi of the north flank of the Bearpaw Mountains, Mont., results from the accumulation of gas in the Eagle Sandstone (Cretaceous) prior to faulting, according to B. C. Hearn, Jr. Studies of electrical logs from 87 wells indicate that the complex fault-block structure of the area was caused by the collapse of sedimentary and volcanic rocks into grabens, above a gravity slide fault in the underlying Colorado Shale (Cretaceous). The gas fields are on structural highs and on detached fault blocks of Eagle Sandstone.

### Statistical analysis of oil and gas data may aid in predicting future production

Oil and gas production data and selected geologic variables are combined by W. W. Mallory in preparing petroleum resource estimates using computer methods of statistical analysis. This statistical method may improve predictions concerning the location and yield of undiscovered oil and gas fields.

<sup>8</sup> Vlissides, S. D., and Quirin, B. A., 1964, Oil and gas fields of the United States, exclusive of Alaska and Hawaii (scale 1:2,500,000): U.S. Geol. Survey, 2 sheets.

### Hydrocarbons in modern sediments

Studies of hydrocarbons in recent sediments of the Choctawhatchee Bay area in northwestern Florida indicate that sand may be more important than mud as a source of petroleum. The distribution of normal paraffin hydrocarbons,  $C_{19}$  to  $C_{33}$ , in estuarine mud and nearshore sand has been shown by J. G. Palacas, A. H. Love, and P. M. Gerrild to be significantly different. In the mud, the odd-carbon-number molecules predominate over the even-carbon-number molecules in a ratio of about 8:1, whereas in most of the sand the ratio is less than 2:1. A comparison of these hydrocarbons with the hydrocarbons in living organisms suggests a land plant source for the hydrocarbons in the mud and a marine source for those in most of the sand. Moreover, the ratio determined for much of the sand is similar to that of the normal paraffins in most crude oils.

## EXPLORATION RESEARCH

Exploration research involved investigation of the mobility of gold in solution in an oxidizing environment, reconnaissance field investigations of geochemical anomalies associated with ore deposits in Colorado, Nevada, and Arizona, studies of the absorption of gold by various plants, studies of the composition, structure and distribution of various minerals in relation to ore deposits, refinements in the use of stream sediment samples for geochemical prospecting, a new technique for expediting the transmittal and processing of field geochemical data, improvement of instrumental methods for detecting mercury and fluorine, and the use of airborne geochemical and geophysical equipment for remote detection of mineralized areas.

### Solution and transportation of gold in an oxidizing environment

The mobility of gold in a supergene environment has been demonstrated by its detection in plant tissues. Plants cannot absorb colloidal gold, and the simple ions  $Au^{+1}$  and  $Au^{+3}$  cannot exist in aqueous solution. Therefore, gold must move as a soluble complex ion in an oxidizing environment. H. W. Lakin, G. C. Curtin, and A. E. Hubert investigated the solution and migration of gold in halide, cyanide, thiocyanate and thiosulfate ion complexes. They concluded that only gold chloride, gold cyanide and gold thiosulfate complexes could be produced in sufficient abundance in the zone of oxidation to play an important role in the transport of gold in solution. Acid solutions resulting from the oxidation of mangiferous pyritic gold deposits may cause the transient mobilization of gold as  $AuCl_4^{-1}$ . In an alkaline carbonate environment sulfur from oxidizing pyrite could combine with gold to

form the soluble  $Au(S_2O_5)^{-3}$  complex, and in soils with high organic content gold may be mobilized as  $Au(CN)_2$ .

### Reconnaissance geochemical investigations

M. A. Chaffee and T. D. Hessin found that copper in the ash of deep-rooted plants growing on shallow alluvium over a porphyry copper deposit in the Vekol Mountains of Arizona was useful in outlining the copper anomaly in this area, but that copper analyses of soil samples and caliche were of negligible value.

Mercury anomalies were found in soils overlying parts of the Montezuma and Caribou stocks of central Colorado by G. J. Neuerburg and Theodore Botinelly. These anomalies may overlie new buried ore deposits.

J. H. McCarthy, Jr., R. E. Learned, and W. H. Ficklin discovered a close association between gold ore and anomalous concentrations of fluorine in rocks of the Cripple Creek district. These fluorine anomalies extend beyond the known gold deposits, suggesting favorable areas for exploration.

In the Empire district of Colorado, anomalous concentrations of gold, copper, bismuth, silver, lead, zinc, and molybdenum in mull, relative to bedrock concentrations of these metals, are reported by G. C. Curtin, H. W. Lakin, and A. E. Hubert. An extensive layer of unmineralized colluvium and glacial drift intervenes between the bedrock and the mull. Other metal anomalies in the mull in this area may overlie blind ore bodies mantled by colluvium and drift.

### Botanical investigations

H. T. Shacklette, H. W. Lakin, A. E. Hubert, and G. C. Curtin demonstrated experimentally the mechanism by which gold is absorbed into plants. Rooted plants and cuttings were placed in halide, cyanide, and thiocyanate solutions containing radiogenic gold ( $Au^{198}$ ), and gold absorption was measured by autoradiographs of the leaves. Of the solutions tested, gold cyanide was most readily absorbed and transported to the leaves. If cyanogenic plants are rooted in auriferous soil, gold may enter the biogeochemical cycle.

### Mineralogical studies

G. J. Neuerburg and Theodore Botinelly observed a decrease in accessory magnetite in peripheral parts of the Montezuma stock in central Colorado where contact metasomatism may have occurred. They noted an association between iron oxide in veins and pneumatolitic bismuth and tungsten deposits in this stock. Neuerburg and Botinelly also report that the cell-edge lengths of gray copper crystals are greatest in deposits with high silver production.

T. G. Lovering, J. R. Cooper, Harald Drewes, and

G. C. Cone (p. B1-B8) found a strong relationship between the copper content of primary biotite, separated from igneous intrusives in southern Arizona, and the proximity of the host rock to copper ore deposits.

Spectrographic analysis of 175 native gold samples, obtained by J. C. Antweiler and W. L. Campbell, showed silver, copper, and mercury in most samples, and iron, titanium, and lead in more than half of them. Ratios of these elements and the presence of certain trace elements, such as palladium and bismuth, in placer gold samples are useful for indicating the lode gold source. Preliminary data suggest a direct relationship between the fineness of lode gold and the temperature at which it was deposited.

#### **Stream-sediment analysis**

Studies of alluvial samples from a mineralized area in the Gila Mountains near Safford, Ariz., by L. C. Huff showed that the nonmagnetic portion of the heavy mineral concentrate from the <80-mesh-sieve size fraction, and also ultrasonic concentrates of grain coatings, are more sensitive for detecting copper anomalies than the unseparated <80-mesh alluvial sample.

W. C. Overstreet (p. D207-D216) noted variations in  $\text{ThO}_2$  and  $\text{U}_3\text{O}_8$  content of detrital monazite concentrates from North and South Carolina that are related to grain size of the concentrates. Coarse-grained monazite contains more  $\text{ThO}_2$  than fine-grained monazite, and extreme differences in grain size also result in large differences in  $\text{U}_3\text{O}_8$  content of monazite. Coarse-grained detrital monazite is likely to reflect primary source rock containing coarse monazite, such as a pegmatite dike swarm. Reported analyses of handpicked detrital monazite separates generally reflect the composition of the coarser grains; thus differences in reported values of  $\text{ThO}_2$  and  $\text{U}_3\text{O}_8$  obtained from such separates are useful in geochemical exploration for coarse-grained primary-thorium or uranium-rich monazite deposits.

#### **Soil and saprolite analysis**

J. W. Whitlow collected 141 bulk grab samples of soil and (or) saprolite in and near the Shuford gold mine in Catawba County, N.C., and compared the analyses of the bulk samples with those of heavy-mineral concentrates recovered by panning the soil and saprolite to wash out the clay, silt, and light minerals. The bulk grab samples contain detectable quantities of all elements present in the concentrate except molybdenum and, possibly, lead. The concentration and collection of heavy minerals from soil and saprolite was not found to be worthwhile except for the purpose of studying those elements present, including molybdenum and, possibly, lead and zirconium. This may not, however, be true for stream sediments. The ana-

lytical results indicate that considerable amounts of most elements present are commonly absorbed on clay minerals and silt-size rock debris which are then lost when the heavy minerals are recovered by panning.

#### **Data transmission and processing**

J. M. Botbol and T. M. Billings successfully transmitted geochemical data on samples collected in the Edna Mountains, Nev., from field headquarters in Winnemucca, Nev., via teletype to the time-share computer in Washington, D.C. The data were recorded on paper tape in a free-field format. The use of this format resulted in a data preparation time which was about 30 percent of that required by conventional card punching. A magnetic data tape was immediately created and available for computer processing of the data.

#### **Instrumental techniques**

A thermoamalgamation technique for the detection of trace amounts of mercury, developed by W. W. Vaughn, was field tested in Yellowstone National Park on samples from streams, thermal springs, fumaroles, and mud pots in geothermal areas. Mercury content ranged from <0.25 ppb in stream samples up to 150 ppm in some mud-pot samples. Interference caused by sulfur was overcome by passing the vapor through a goldfoil amalgamator at about 150°C and selectively trapping mercury, which was then released at about 600°C for quantitative determination.

W. H. Ficklin (p. C186-C188) reported that a fluoride ion-selective electrode provides an effective rapid method for determining small amounts of fluorine in rocks. This instrument was used in detecting fluorine anomalies associated with gold deposits in the Cripple Creek district of Colorado.

#### **Airborne detection**

An airborne mercury detector developed by J. H. McCarthy, Jr., R. E. Learned, W. W. Vaughn, J. L. Meuschke, and W. H. Ficklin<sup>9</sup> revealed anomalous concentrations of mercury over several base- and precious-metal deposits in Arizona. A similar device also showed reproducible mercury anomalies in soil gas over mercury deposits in the Ivanhoe district, Nevada. However, W. W. Vaughn reported that the 80-mesh silver screen used in this apparatus to trap mercury vapor by amalgamation has an efficiency of less than 10 percent at the flow rate and geometry used in the airborne technique, making reproducibility of results difficult. Experimental research to improve the efficiency of the detector is now in progress.

<sup>9</sup> McCarthy, J. H., Jr., Vaughn, W. W., Learned, R. E., and Meuschke, J. L., 1969, Mercury in soil gas and air—A potential tool in mineral exploration: U.S. Geol. Survey Circ., 609, 16 p.

F. C. Frischknecht designed a stabilized antenna mount, a balanced horizontal electric dipole antenna, and a preamplifier for use with a commercial airborne VLF radio-wave receiver for measuring changes in the horizontal electric field related to changes in conductivity and thickness of the overburden.

### OFFICE OF MINERALS EXPLORATION

The U.S. Geological Survey, through its Office of Minerals Exploration (OME), conducts a program to encourage exploration for domestic mineral reserves, excluding organic fuels, by providing financial assistance through exploration loans to private industry on a participating basis under Public Law 85-701. 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 own, lease, or have an otherwise valid right to possession of the property he wishes to explore for a period of time at least sufficient to complete the exploration work. A reasonable geologic probability must exist of a significant discovery of ore being made on the property by the proposed exploration. Repayment of Federal funds expended on a contract plus simple interest is made through a 5 percent royalty on mineral production from the property 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 there is no production, no repayment is required. The Government is not obligated to purchase any production.

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

Asbestos	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.

Activity on the OME program in calendar year 1969, and totals for the program through December 31, 1969, were as follows:

Activity	Calendar year 1969	Program totals 1969 through 1969
Applications:		
Received.....	46	1 836
Denied.....	19	337
Withdrawn.....	24	282
Processing completed.....	54	800
Total in process, Dec. 31, 1969..	36	-----
Contracts:		
Executed.....	11	181
Total value.....	\$625, 530	\$11, 713, 587
Government share.....	\$315, 443	\$6, 691, 867
Government share spent.....	2 \$582, 966	\$3, 831, 264
Repaid to Government through royalties on production.....	\$82, 994	\$256, 770
Estimated value of reserves discovered on certified projects..	\$37. 6 million	\$124 million

1 Total estimated cost of proposed exploration, \$81,927,120.

2 Expenditures on all active contracts during the year.

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.....	66	\$5, 018, 509	42. 8
Gold.....	51	2, 621, 149	22. 3
Mercury.....	15	1, 100, 780	9. 4
Copper.....	12	709, 050	6. 1
Lead-zinc.....	7	682, 030	5. 8
Lead-zinc-copper.....	11	487, 641	4. 2
Molybdenum.....	3	384, 438	3. 3
Iron.....	3	199, 580	1. 7
Beryllium.....	3	127, 440	1. 1
All others (cobalt, fluorspar, mica, nickel, platinum, uranium).....	10	382, 970	3. 3
Total (15 commodities).....	181	11, 713, 587	100. 0

### 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 suitability

studies, the U.S. Geological Survey and the U.S. Bureau of Mines are making mineral surveys of primitive areas of the national forest which are being considered for wilderness inclusion. The Geological Survey and Bureau of Mines also are making mineral surveys of wilderness areas that were established by the Wilderness Act.

### PRIMITIVE AREAS

A total of 34 primitive areas are identified with the Wilderness Act, which specifies that reports on these areas are to be completed at a prescribed rate and submitted to the President and the Congress within 10 years of the enactment of the Act. As of June 1970, the U.S. Geological Survey and U.S. Bureau of Mines had completed mineral surveys of 16 primitive areas and had published the results as Geological Survey bulletins. The 16 primitive areas are as follows: San Rafael, Calif.; Sycamore Canyon, Ariz.; Flat Tops, Colo.; Spanish Peaks, Mont.; Mount Jefferson, Oreg.; Stratified, Wyo.; Mount Baldy, Ariz.; Pine Mountain, Ariz.; Devil Canyon-Bear Canyon, Calif.; Ventana, Calif.; Desolation Valley, Calif.; High Uintas, Utah; Uncompahgre, Colo.; Mission Mountains, Mont.; San Juan-Upper Rio Grande, Colo.; and Blue Range, Arizona and New Mexico. Mineral surveys on the Pasayten Wilderness, Wash. (formerly part of the North Cascades Primitive Area); and the Sawtooth, Idaho; Emigrant Basin, Calif.; Black Range, N. Mex.; Agua Tibia, Calif.; and Gore Range-Eagle Nest, Colo., Primitive Areas have been completed, and the reports were in press as of June 1970.<sup>10</sup> Studies are underway on nine other primitive areas.

The mineral surveys are aimed primarily at appraising the mineral potential of the areas. The work includes reconnaissance geologic mapping and extensive stream sediment and rock sampling. During calendar

year 1969, a total of 197,537 analytical determinations were made from 12,358 samples collected in wilderness program studies.

Reports were published for two primitives areas during the year: San Juan-Upper Rio Grande, Colo., and Blue Range, Arizona and New Mexico.

### San Juan-Upper Rio Grande, Colo.

The adjoining San Juan and Upper Rio Grande Primitive Areas are in southwestern Colorado. Because of their proximity to each other, the two areas were studied as a unit. Gold, silver, copper, lead, zinc, uranium, and sulfur, valued at about \$257,000, have been mined within or near the area with most of the value produced from the Beartooth (Bear Creek) mining district along the northwestern margin of the area.

T. A. Steven, L. J. Schmitt, Jr., M. J. Sheridan, and F. E. Williams (r0163) described the western part of the area as underlain by Precambrian metamorphic rocks which are intruded by granitic rocks. Most of the remainder of the area is covered by volcanic rocks of middle Tertiary age.

Evidence of mineral deposits of commercial or near commercial value was found in 4 localities:

1. The Chicago Basin of the Needle Mountains mining district contains disseminated molybdenite in an intrusive stock. Older surrounding rocks are cut by numerous veins, some of which have economic potential.
2. Whitehead Gulch, in the northwestern part of the area, contains many small veins and sporadic deposits, some of which are of commercial grade.
3. The Beartown mining district contains a number of veins that yielded high-grade ore in the late 1800's. Exploration targets exist in the area.
4. The Trout Creek-Middle Fork Piedra River area contains native sulfur deposits in highly altered volcanic rocks.

Aeromagnetic data, which were not available in time to be included in the report by T. A. Steven and others (r0163), were evaluated, and a map and short report on the area by Peter Popenoe and T. A. Steven (r0664) were placed in open file. The open-file map illustrates anomalies near the Chicago Basin and along the north side of the area that cannot be accounted for by surface geology and which may reflect intrusive bodies at depth.

### Blue Range, Arizona and New Mexico

The Blue Range Primitive Area covers about 380 sq mi in southeastern Arizona and southwestern New Mexico. No evidence of potential mineral resources was found in more than 90 percent of the area by J. C.

<sup>10</sup> Staats, M. H., Weis, P. L., Tabor, R. W., Robertson, J. F., Van Noy, R. M., Pattee, E. C., and Holt, D. C., 1971, Mineral resources of the Pasayten wilderness area, Washington, with a section on Aeromagnetic interpretation by G. P. Eaton and M. H. Staats: U.S. Geol. Survey Bull. 1325 [In press]

Killsgaard, T. H., Freeman, V. L., and Coffman, J. S., 1970, Mineral resources of the Sawtooth primitive area, Idaho: U.S. Geol. Survey Bull. 1319-D, 174 p. [published July 1970]

Tooker, E. W., Morris, H. T., and Fillo, P. V., 1970, Mineral resources of the Emigrant Basin primitive area, California, with a section on Geophysical studies, by H. W. Oliver: U.S. Geol. Survey Bull. 1261-G, p. G1-G70. [published July 1970]

Ericksen, G. E., Wedow, Helmuth, Jr., Eaton, G. P., and Leland, G. R., 1970, Mineral resources of the Black Range primitive area, Grant, Sierra, and Catron Counties, New Mexico: U.S. Geol. Survey Bull. 1319-E, 88 p. [In press]

Irwin, W. P., Greene, R. C., and Thurber, H. K., 1970, Mineral resources of the Agua Tibia primitive area, California: U.S. Geol. Survey Bull. 1319-A, 19 p. [published July 1970]

Tweto, Ogden, Bryant, Bruce, and Williams, F. E., 1970, Mineral resources of the Gore Range-Eagles Nest primitive area and vicinity, Summit and Eagle Counties, Colorado: U.S. Geol. Survey Bull. 1319-A, 19 p. [published July 1970]

Ratté, E. R. Landis, D. L. Gaskill, and R. G. Raabe (r0161). Hydrothermally altered rocks and low-level anomalous concentrations of metals in the Red Mountain-Oak Creek and the Squaw Creek-Maple Canyon areas indicate that ore deposits may occur at depth. Available evidence indicates that the Squaw Creek-Maple Canyon area has much the greater potential, particularly for molybdenum and copper. The mineral potential of the area is further highlighted by a pronounced magnetic high, described by J. C. Ratté and others (r0161) and in further detail in an open-file report by G. P. Eaton and J. Ratté (r0646).

The mineral survey report concludes that concealed mineral deposits could occur elsewhere in the proposed wilderness, buried at depth beneath younger volcanic rocks, but no supporting evidence for such deposits was found at the surface. The likelihood of mineral fuel deposits in the area is slight.

#### WILDERNESS AREAS

Mineral surveys have been started in the Gila Wilderness, N. Mex., and the Bob Marshall Wilderness, Mont. Studies in other wilderness areas will begin as work in primitive areas is completed. Mineral resources of the Jack Creek basin, Montana, which is being considered for inclusion in the National Wilderness Preservation System, were completed by G. E. Becraft, T. H. Kiilsgaard, and R. M. Van Noy (r1965).

#### RESOURCE COMPILATIONS

##### UPPER YUKON-TAIYA PROJECT, ALASKA

Mineral resources relevant to the power market potential of the Upper Yukon-Taiya study area in central and southeastern Alaska are described in an administrative report prepared for the Alaska Power Administration. The report was prepared by the U.S. Geological Survey under the direction of A. E. Weissenborn. It includes a section, "Electric Power Requirements of an Expanded Mineral Industry," by the U.S. Bureau of Mines.

The area considered in the report is regarded by the Alaska Power Administration as a potential market for power that would be developed by a proposed Upper Yukon-Taiya River hydroelectric project now being studied by the Alaska Power Administration. It includes all of Alaska south and east of the Alaska Railroad, the Steese Highway, and the Yukon River east of Circle—an area of about 147,000 sq mi of terrain, much of which is rugged, relatively inaccessible, and generally sparsely inhabited. All of the area is within 600 miles of Skagway.

The report summarizes the geology of the area

studied. It reviews the mineral potential of the region on a commodity basis and discusses the possibility for mineral discoveries in each of nine geographic subareas into which the area has been divided. The area has been an important source of gold and copper. It has produced lesser amounts of other metallic and nonmetallic commodities; production of these commodities, however, has declined drastically in the last few years. In contrast, the region has become an important producer of petroleum products; coal production set a new record in 1968, and output of construction materials has increased greatly. Mineral exploration has been increased in the area in recent years and if these efforts continue, significant mineral discoveries should result, which could lead to expansion of the metallic and non-metallic mineral industry. Power requirements for the mineral industry within the next 20 years may be as much as 293 Mw, or 2,688 kwhr/yr.

#### RESOURCES OF THE GREAT BASIN REGION

Figures on the quantity, quality, and extent of the more significant mineral resources in the Great Basin region were assembled by L. S. Hilpert, in cooperation with Federal and State agencies, for inclusion in Appendix VII of an administrative report entitled "Comprehensive Framework Studies of the Great Basin Region." These studies are prepared for the Pacific Southwest Interagency Committee, Water Resources Council, and are one of 20 such studies for the United States.

The mineral resources are tabulated under known resources and predicted additional resources, and are classified under geologic types of deposits. They also are discussed by mineral commodity and by subregions. The Great Basin region includes most of Nevada, western Utah, and adjoining parts of southeast Idaho and southwest Wyoming.

#### ENERGY RESOURCES

M. K. Hubbert's review, "Energy Resources," (r2578) in the report of the National Academy of Sciences-National Research Council Committee on Resources and Man, is a part of a continuing study begun more than 30 years ago. This review brings up to date his earlier study<sup>11</sup> made as a member of the National Academy of Science Committee on Natural Resources, advisory to President John F. Kennedy.

The principal conclusions from this study are that the period of exponential industrial growth that the world has experienced during the last two centuries can hardly be continued for more than another century

<sup>11</sup> Hubbert, M. K., 1962. Energy resources, a report to the committee on natural resources: National Academy of Sciences-National Research Council Pub. 1000-D, 141 p.

or so into the future. The reason for this is that an exponential increase of any physical quantity—energy consumption, industrial output, or a biological population—involves successive doublings in equal intervals of time, and only a small number of such doublings is possible before the resources of a finite earth will be exceeded. Hence, viewed on a time span of a few thousand years, past and future, the present period of rapid growth will probably represent but a brief episode of about three centuries duration between two very much longer periods characterized by very slow rates of change.

With the energy available from nuclear sources, it is physically and biologically possible that a future period of stability at a comfortably high rate of energy consumption per capita may be achieved, but to do so will probably require some profound adjustments of mores based upon the premises of indefinitely continued exponential growth.

#### SEABED RESOURCES

During 1970, V. E. McKelvey and J. I. Tracey, Jr., represented the United States at meetings of the Economic and Technical Subcommittee of the United Nations Committee on the Peaceful Uses of the Seabeds and Ocean Floor Beyond the Limits of National Jurisdiction, and presented several papers on subsea mineral resources and problems related to their development (those given at the March meeting are published in Geological Survey Circular 619, V. E. McKelvey and others, r0084). To assist the United States and other nations in understanding the distribution and magnitude of potential seabed resources, McKelvey and F. H. Wang (r2527) also compiled a series of maps showing their world distribution. These maps, and a pamphlet accompanying them, indicate that the areas favorable for petroleum are mainly the continental shelves and slopes, the small ocean basins, and the continental rises. Potential subsea resources of petroleum in these geologic provinces are as large and perhaps larger than those of the continents, and areas favorable for petroleum occurrence lie adjacent to nearly every coastal nation. Other minerals from the continental shelves include heavy-mineral concentrates (placers), sand, gravel, shell, phosphorite, and lime mud minable by dredging in shallow water near shore; coal, iron, copper, limestone, and a few other minerals minable underground from a land or artificial-island entry; and sulfur, salt, potash, magnesium, fresh ground water, and geothermal energy recoverable through drill holes. Potential resources on and beneath the deep ocean floor include manganese oxide nodules and other metalliferous deposits and are an enormous potential source of

manganese, copper, nickel, cobalt, zinc, and other metals.

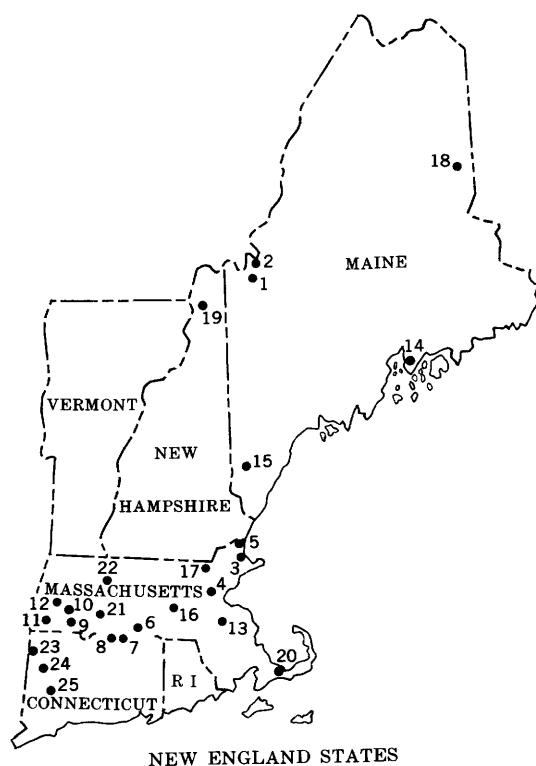
## GEOLOGICAL, GEOPHYSICAL, AND MINERAL-RESOURCE STUDIES

### NEW ENGLAND

#### STRUCTURAL AND STRATIGRAPHIC STUDIES

##### Paleotectonic features of western Maine

Major paleotectonic features of western Maine apparently controlled both sedimentation and the evolution of the dominant structural pattern during Paleozoic time. According to R. H. Moench the stratigraphic thicknesses and lithofacies relationships in the Rangeley-Rumford area (locality 1, index map) indicate that lower and middle Paleozoic clastic sedimentary rocks were derived largely from the persistent Somerset geanticline on the northwest, and accumulated in an equally persistent northeast-trending trough whose axis was a short distance to the southeast. These clastic rocks are deformed by major faults and folds that conform to the larger paleotectonic pattern. The faults are normal faults, downthrown on the southeast toward deeper parts of the sedimentary basin; major folds appear to be geometrically and genetically related to these normal down-to-basin faults. Moreover, the presence of metamorphosed clastic dikes subparallel to





axial plane slaty or phyllitic cleavage indicates that the sediments were mobile and water bearing during folding and cleavage formation. The tightness of the folds may, in fact, reflect the directional volume decrease that accompanied the expulsion of pore water.

The fault-fold pattern is inferred to have evolved over a long period of time, approximately as follows: (1) Rapid deposition of 15,000 to 20,000 feet of nearly impermeable clastic sediments in Late Ordovician and Early Silurian time on the southeast-dipping slope of the sedimentary trough; the mass weakened at depth by excess fluid pressure. (2) Continuing sedimentation, down-to-basin creep with associated slump faulting and folding, probably beginning in Middle Silurian time; faults flattened basinward at depth along lower boundary of the zone of excess fluid pressure. (3) Horizontal compression developed parallel to slide direction as the mass piled against material in the trough; incipient slaty cleavage developed normal to compression, improving vertical permeability. (4) Pore fluids were expelled vertically, permitting the slumping mass to compact horizontally and fold with at least 30-percent shortening. The process culminated in Early Devonian time, during and after deposition of the youngest exposed rocks in the area.

#### **Probable Precambrian in western Maine**

Mapping by E. L. Boudette in the Chain Lakes quadrangle (loc. 2) substantiated an earlier hypothesis that the pre-Silurian layered rocks in northwestern Maine are divisible into two major sequences. This separation is based to a large extent upon distinct lithologic differences, as well as on the contrasting response of rocks in each of the sequences to contact metamorphism related to an alpine ultramafic massif intruded conformably into both sequences, probably in Early Ordovician time. Quartz-feldspar-mica sillimanitic gneiss on the northwestern side of the massif shows an increase in white mica and grain size toward the contact. The southeastern side of the massif is in contact with eugeosynclinal rocks in the greenschist facies, and maculose rocks are developed in the thermal aureole; reaction hornfels occurs near the massif rocks. Contact metamorphism in the gneiss is tentatively interpreted to be a retrograde effect, but in the greenschist rocks it appears to be a normal prograde effect. Thus, prior to the intrusion of the massif, the two metamorphic rock sequences must have coexisted spatially, possibly separated by an unconformity, or at least with a profound metamorphic hiatus, and with the gneiss in the older sequence. This contrast may be demonstrated in a single outcrop on Bag Pond Mountain where a greenstone dike intrudes gneiss of the complex, providing the

lithologic correlation with greenstone effusives to the south in the greenschist sequence is a valid one.

The older sequence is interpreted to be a basement complex, probably Precambrian(?) to Cambrian(?) in age. It is subdivided into two stratigraphically younger units consisting of well-layered metamorphosed volcanic and clastic sedimentary rocks at least 8,000 feet thick and three probably older units consisting mainly of massive fragmental rocks of unusual texture and structure at least 2,000 feet thick. These units appear to be conformable, upright, and facing southeastward. Quartz monzonite and granodiorite of the Seven Ponds pluton of Devonian age intrude the rocks of the complex with a sharply defined conformable contact on the crest of the Boundary Mountains anticlinorium. Quartz veins are a widespread feature of the complex, and these appear to be more abundant and richer in pyrite and pyrrhotite near the contact with the Devonian intrusive. Placer gold in streams that drain the complex may owe its origin to the quartz veins.

The younger greenschist sequence is assigned a Cambrian(?) to Ordovician(?) age. It is subdivided in stratigraphic order, from oldest to youngest, into the low-grade metamorphic equivalents of: (1) mafic volcanics, (2) quartz latite, (3) graywacke, intermediate and mafic volcanic rocks, and iron-formation, (4) dark euxinic pelite and graywacke, and (5) laminated chloritic phyllite and calcareous to chloritic sandstone and quartzite. This sequence also is upright and faces southeast, and represents an environment favorable for the occurrence of copper and zinc comparable to that of the Bathurst area of New Brunswick. To date only disseminated pyrite and pyrrhotite have been found. Notable amounts occur north and east of Shallow Pond near the Attean Quartz Monzonite of probably Early Ordovician age.

#### **Stratigraphy of the Marlboro Formation in eastern Massachusetts**

The lower volcanic unit of the Marlboro Formation was traced by K. G. Bell for about 45 miles intermittently from the Massachusetts coast in the Ipswich quadrangle (loc. 3) southwestward to the Natick quadrangle (loc. 4). This unit consists of basic tuffs and pillow lavas that were metamorphosed to amphibolites throughout most of this distance. The contact zones between intrusive igneous rocks and this volcanic unit of the Marlboro commonly are sites of low-grade iron-copper-lead-zinc sulfide mineralization. The sulfide minerals may occur through distances of a few feet along either side of a contact throughout an intrusion breccia zone, and are associated with igneous rocks ranging in composition from granodiorite to gabbro.



No deposit of economic importance has been observed. Prior to 1850 some of these deposits in the Georgetown and Lexington quadrangles were tested by digging trenches and shallow pits.

N. P. Cuppels divided the Marlboro Formation in the Concord quadrangle and elsewhere in Middlesex County, Mass., into six sequences of lithologic units that have distinctive compositions and fabrics. Evidence indicates that the age of the Marlboro Formation is Cambrian and Ordovician rather than the less specific pre-Devonian.

#### Structure of northeastern Massachusetts

Bedrock mapping in eastern Massachusetts during 1969 provided additional information on the great imbricate thrust fault zone of the area (U.S. Geol. Survey, R0424, p. A21-A22). The major faults have been known for several years, but many of the smaller ones are being recognized only as mapping progresses. The major faults of the area are the Northern Boundary fault of the Boston basin and the unnamed faults bounding the Newbury basin. A few years ago it was recognized that a fault zone extends from the hanging wall side of the Northern Boundary fault of the Boston basin in the Lexington quadrangle northeastward through parts of the Boston North, Reading, Salem, and Georgetown quadrangles to the footwall side of a large fault on the south side of the Newbury basin. Work along the fault zone in the Georgetown and Salem quadrangles during 1969 has shown the presence of several large slivers having widths of as much as a mile and lengths from half a mile to 3 or 4 miles. Identification of rock units by petrographic methods has been useful to K. G. Bell in defining several minor faults in the Reading and Wilmington quadrangles.

A. E. Nelson found that two major faults are present in the Natick quadrangle. One, a northeast-trending fault, extends into the Border fault and separates pre-Carboniferous from Carboniferous rocks; the other, an east-trending fault, extends across the northern part of the quadrangle. Several smaller faults parallel this east-trending fault to the south, and together they form a major fault zone. Most of the east-trending faults have right-lateral displacement, and the largest appears to have a displacement in excess of 7 miles. This fault is a major structural feature of eastern Massachusetts and shows up as a distinct lineament on aeromagnetic maps of both the Natick quadrangle and the adjoining Framingham quadrangle to the west. In the Newton quadrangle, this fault divides pre-Carboniferous from Carboniferous rocks, and merges here with the northeast-trending Border fault.

Recognition by A. F. Shride in the Newburyport East quadrangle (loc. 5) of a distinctive sequence of basalt flows, rhyolite(?) tuffs, and intermediate flows and pyroclastics in the Newbury Formation of Silurian or Devonian age resulted in more definitive and simpler interpretation of fault patterns at the northeast end of this structural zone.

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

G. E. Moore, Jr., found that the Brimfield Schist of the Southbridge quadrangle, Massachusetts (loc. 6), contains separately mappable units of quartz-feldspar-garnet-sillimanite schist and gneiss, lime-silicate rocks, and metavolcanic rocks. The underlying Paxton Quartz Schist, mostly quartz-feldspar-biotite gneiss, has not been subdivided. Both formations contain many pods of foliated quartz-feldspar pegmatite. The contact between the Brimfield and Paxton in this quadrangle appears to be a gradational sedimentary contact; there are, however, strike faults in both formations.

On the basis of the first detailed mapping of the entire structural and stratigraphic sequence across the Brimfield Schist near the Massachusetts-Connecticut line (loc. 7), J. D. Peper concluded that the Brimfield probably consists of rocks of both Silurian-Devonian and Middle Ordovician age that have been imbricated by major north- and northeast-trending thrust faults. Internal structural complications preclude simple tracing of rocks in the type locality of the Brimfield Schist southward into the Brimfield of southern Connecticut. Furthermore, the structural pattern thus far worked out for the belt suggests that the recumbent fold pattern previously assumed for southern Connecticut cannot be simply extended northward to include the Brimfield rocks in the northern part of the State.

According to M. H. Pease, Jr., the Glastonbury Gneiss intrudes the Monson Gneiss (Ordovician(?)) west of the Bronson Hill anticline in the Stafford Springs quadrangle (loc. 8) in Connecticut. This is the first report of this rock type on the east side of the anticline. It is a pre-tectonic intrusion typified by dual foliation, fracturing, and granulation of mineral grains. On this basis the Glastonbury is correlated with the Oliverian Plutonic Series that intrudes Ordovician strata in many of the domes of New England.

The contact between rocks of the Bronson Hill anticline and Emerson's<sup>12</sup> Brimfield Schist is a fault contact as mapped by Pease between its exposure at two localities in the Stafford Springs quadrangle. Poorly preserved sedimentary features in these rocks suggest

<sup>12</sup> Emerson, B. K., 1898, *Geology of old Hampshire County, Mass., comprising Franklin, Hampshire, and Hampden Counties*: U.S. Geol. Survey Mon. 29, 790 p.

that they are mostly right side up. If this contact is a fault throughout Massachusetts and Connecticut and not a structurally inverted stratigraphic contact there is no basis for the interpretation by previous workers in Connecticut that the rocks east of the Bronson Hill anticline are upside down.

#### **Structure of northern Connecticut and southern Massachusetts west of the Connecticut River**

Mapping in the Southwick, New Hartford, and West Granville quadrangles in Massachusetts and Connecticut (loc. 9) by R. W. Schnabel disclosed two north-trending doubly plunging anticlines that are delineated by several thick mappable metavolcanic and meta-sedimentary units. Small-scale folds are locally common in some of the units, but detailed mapping of distinctive, individual beds over strike distances of several miles implies they do not materially affect the map pattern. Study of relict sedimentary structures implies a simple right-side-up structural picture. This sequence of rocks is bounded to the east by the Triassic basin, and to the west by a major topographic lineament which is interpreted as a large-scale fault. Units west of the fault are lithologically correlatable with units mapped to the north in Massachusetts and Vermont. East of the fault correlation with rocks mapped to the north is not possible on a lithologic basis. Patterns on aeromagnetic maps correspond very well with the geology as mapped.

A new Middle Silurian(?) marker unit was discovered and defined, and north-south facies changes in the Middle Ordovician rocks were mapped out in detail near Blandford, Mass. (loc. 10), by N. L. Hatch, Jr., S. F. Clark, Jr., and R. S. Stanley. As a result, a correlation is made between the sequence near Blandford and the one mapped previously by Stanley in the Collinsville area, west-central Connecticut. Many units mapped as Cambrian or Ordovician in southwestern Connecticut are now considered correlative with the Russell Mountain Formation<sup>13</sup> (Silurian) or the Goshen Formation (Silurian and Devonian) of Massachusetts.

#### **Thrust faults in Connecticut, New York, and Massachusetts**

Mapping by D. S. Harwood along the western front of the Berkshire Highlands in Berkshire County, Mass., and Litchfield County, Conn. (loc. 11), showed that the gneiss complex of the Berkshire Highlands and part of the carbonate and quartzite miogeosynclinal sequence is recumbently folded and thrust west-

ward over the Stockbridge Formation (Cambrian and Ordovician) and the Walloomsac Formation (Middle Ordovician). Four gently eastward dipping imbricate thrust slices have been recognized to date along the western front of the highlands. The higher slices appear to be rooted eastward in southeast-trending high-angle reverse faults that transect the Berkshire Highlands.

At the latitude of Stockbridge, Mass. (loc. 12), according to N. M. Ratcliffe (r0292), the western edge of the Berkshire Highlands massif makes an abrupt swing to the west in the vicinity of Beartown Mountain, offsetting the Precambrian front approximately 5 miles to the west. Detailed mapping in this area of the Precambrian front in the Stockbridge, Great Barrington, Monterey, and Ashley Falls quadrangles, Berkshire County, indicates the existence of large-scale nappe structures and faulted nappes having westward tectonic transport directions. The Cheshire Quartzite (Lower Cambrian) and Dalton Formation (Lower Cambrian (?)) formed the cover of a large faulted anticlinal structure known as the Beartown Mountain nappe. Assuming a thrust direction from the northeast to southwest, the minimum amount of horizontal transport was 7 miles. It appears likely that large parts of the Precambrian and Lower Cambrian clastic rocks in southwestern Massachusetts are not rooted and occur in widespread thrust sheets resting on the autochthonous Stockbridge or Walloomsac Formations.

Two episodes of regional metamorphism were deduced by E-an Zen for the southwestern corner of Massachusetts and adjacent areas of New York and Connecticut on the basis of mineralogic and textural relations in the rocks. Field mapping also showed that the area has undergone at least two periods of folding and cleavage development; two periods of thrust faulting, of which the earlier was gravity sliding, whereas the later involved thrusting of brittle rocks; and one period resulting in regional unconformity. Relations among the various features indicate the relative chronology to be as follows, from old to young: regional unconformity, gravity sliding, brittle thrusting with concomitant early folding, metamorphism, and second folding with concomitant second metamorphism. The unconformity and gravity sliding have been paleontologically dated as Middle Ordovician (Trenton). The second metamorphism and folding (last event of the list) have been isotopically dated as Acadian orogeny (Early to Middle Devonian). That the early regional metamorphism took place between the two periods of metamorphism is confirmed by isotopic mineral dates in western New England and eastern New York that indicate the existence of an episode of metamorphism

<sup>13</sup> Hatch, N. L., Jr., Stanley, R. S., and Clark, S. F., Jr., 1970. The Russell Mountain Formation, a new stratigraphic unit in western Massachusetts: U.S. Geol. Survey Bull. 1324-B. [In press]

in Late Ordovician to Early Silurian time, an assignment in agreement with the data from the Cortlandt Complex area near Peeksville, N.Y.<sup>14</sup> The second thrusting then must be an Ordovician or Taconic event in agreement with deductions by field workers in eastern Pennsylvania and nearby New Jersey. This chronology substantially revised earlier estimates of the diastrophic role of the Taconic orogeny in western New England, and provides a reasonable basis for interpretation of several puzzling field relations in the Vermont part of the Taconic allochthon.

#### **Carbonate-clast conglomerates in Appalachian orogenic belt**

Various types of carbonate-clast conglomerates, of Cambrian and Ordovician age, occur on the west side of the Appalachian orogenic belt. Those extending from northwestern Newfoundland to the Potomac River have been studied by E-an Zen in cooperation with J. M. Bird (State University of New York at Albany). Clasts in conglomerates range in size from more than 150 m to but a few millimeters across; the matrix varies in composition from quartz and calcite sand to shale, and the amount present varies from very little to volumetrically predominant. The clasts may all be the same age in a given bed, or they may represent many ages; some conglomerates include clasts of Precambrian basement rocks. The conglomerates are interbedded with limestone and (or) shale, and where original spatial relations can be discerned they are located at the facies junction between shelf deposits and basin deposits. A model has been constructed for the sedimentary environments of the different conglomerates. Pre-tectonic conglomerates occur on the shelf, along the brink of the shelf against the basin as slump deposits from the shelf front, and as increasingly finer clasted and thinner conglomerates in the basin deposits (many of these are preserved in allochthons only). Syntectonic conglomerates include several varieties of basal conglomerates as well as the shelf, brink, and basin conglomerate types having smaller geographic and stratigraphic extent owing to the more restricted and rapidly evolving sedimentary environments. The various types of conglomerates can generally be recognized by their petrographic characteristics; all presently known conglomerates can be assigned to the implied geographic settings without conflict with field evidence. These characteristics of conglomerates should be useful tools in future paleogeographic

reconstructions for this part of the Appalachian region.

### **STUDIES OF IGNEOUS ROCKS**

#### **Gabbro at Ashland, Mass.**

The contact of a large gabbroic body with quartzites and slates is well exposed in the B and M stone quarry at Zachary Hill in Ashland, Middlesex County (loc. 13). The contact is marked by stringers of chilled gabbro extending into the lowest quartzite unit, extreme induration of the quartzite, and presence of spotted slates. The east-dipping quartzite and slate are thought by R. P. Volckmann to represent the upper part of the Westboro Quartzite. If this is true, the area between Zachary Hill and Paul Hill, 5 miles to the east, should be underlain by Marlboro rocks except where the section has been spread or eliminated by granitic intrusion.

### **MINERALOGIC AND ISOTOPIC STUDIES**

#### **Age of volcanic rocks, Castine-Cape Rosier area, Maine**

The age relationships between three volcanic sequences that rest upon metamorphosed unfossiliferous basement rocks in the Castine-Cape Rosier and Cranberry Island regions (loc. 14) and upon fossiliferous sediments on North Haven, Vinalhave, and Stimsons Island were investigated by the Rb/Sr method by D. G. Brookins and Sambhudas Chandhuri (Kansas State University) and D. B. Stewart. The results yield least-squares isochrons that are indistinguishable within the limits of error, and indicate ages of 396 to 410 m.y., with very similar initial  $\text{Sr}^{87}$ - $\text{Sr}^{86}$  ratios. These results suggest that these volcanic rock sequences should be correlated. Good agreement is shown between the isotopic age and a preliminary paleontologic age, by A. J. Boucot (Oregon State University) and J. M. Berdan, of the fossiliferous sediments (Upper Silurian-Pridoli).

### **GRAVITY AND AEROMAGNETIC STUDIES**

#### **Basement rocks, Gulf of Maine**

Analysis of gravity and aeromagnetic data of the Gulf of Maine by M. F. Kane indicates that the crustal block underlying the Gulf of Maine is distinctly different from the surrounding region of the Appalachians. The mass contrast which differentiates the Gulf block is in the upper crust. Mafic rocks are prevalent throughout the Gulf but appear to be most abundant along the northwest and southeast coastal regions. The bedrock can be divided into at least four separate regions on the basis of the contrast in these magnetic fields. The dominant trends are northeast in

<sup>14</sup> Ratcliffe, N. M., 1968, Stratigraphic and structural relations along the western border of the Cortlandt intrusive, in Finks, R. M., ed., Guidebook to field excursions: New York State Geol. Assoc., 40th Ann. Mtg., Flushing, N.Y., 1968, p. 197-220.

accord with the Appalachian trend, but both east and north lineaments are also apparent.

#### **Sebago pluton, southern Maine**

The large felsic Sebago pluton of southern Maine (loc. 15) lacks the pronounced negative gravity anomaly that is commonly associated with the other large felsic plutons in the region to the north. A continuous ground magnetic profile indicates that the pluton is cut by a great number of dikes, and in this respect differs from the other plutons. Studies by M. F. Kane to date indicate that the lack of anomaly over the Sebago pluton is a result of the shallowness of the pluton, and it may be that the ubiquitous dikes and thinness of the pluton are related phenomena.

#### **Linear magnetic discontinuity, eastern Massachusetts**

A pronounced linear magnetic discontinuity extends northeastward from the Worcester area (loc. 16) through parts of eight quadrangles to the vicinity of Lowell, Mass. (loc. 17). West of the discontinuity the magnetic pattern is characterized by a relatively gentle south to southeast sloping field with widely separated, broad, low-amplitude anomalies. East of the discontinuity the magnetic pattern is characterized by closely spaced, steep-sided, high-amplitude magnetic highs and lows elongate in a northeast direction. Mapping in the Clinton quadrangle by J. H. Peck and in the Westford, Lowell, and Billerica quadrangles by D. C. Alvord indicates a major fault along the line of abrupt change in magnetic pattern. Rocks on the southeast side of the fault are mostly sillimanite-grade gneisses and schists. Rocks on the northwest side include granitic intrusives and relatively low-grade metasedimentary and metavolcanic rocks. Rocks within the fault zone are highly sheared and crushed, and locally silicified. Displacement along the fault is unknown, but apparently the rocks on the northwest have been thrust over the rocks on the southeast. The linear nature of the fault trace and the magnetic discontinuity indicates that the fault is at a fairly high angle between Worcester and Lowell and may continue northeastward at a much lower angle. Probably the fault extends from at least as far south as Connecticut northeastward through Newburyport, Mass., and into the Gulf of Maine.

### **PLEISTOCENE GEOLOGY**

#### **Esker systems, northern Maine**

Compilation of the surficial geology of the Howe Brook, Smyrna Mills, and Houlton quadrangles, Maine (loc. 18) by Louis Pavlides shows a different pattern of esker extent and trend than that originally mapped

by Leavitt and Perkins.<sup>15</sup> Three well-developed esker systems in the Houlton quadrangle have been actively exploited for sand and gravel and are of particular interest. They transect the quadrangle in both a southeast- and a south-trending direction and commonly are bounded by ice-contact deposits that include kame fields and kame terraces. Two of the esker systems merge a few miles northeast of Houlton and continue to the south as a single esker system. This esker system was considered by earlier workers to continue southward for over 100 miles to Lake Meddybemps, near Calais, Maine. Recently completed mapping, however, indicates that this esker system turns to the east a few miles south of the Houlton quadrangle and crosses into New Brunswick rather than continuing southward to Lake Meddybemps.

The Houlton eskers commonly rest directly on polished bedrock surfaces, and in places along their course are pitted by ice kettle holes. Eskers with such features are believed to have formed within ice tunnels at the base of thin stagnant ice. Ice blocks falling into the esker tunnels formed the ice kettle holes when the ice blocks eventually melted.

#### **Pleistocene history, Nash Stream, N.H.**

Several new exposures, resulting from a catastrophic flood (discharge in excess of 20,000 cfs) after an earth-fill dam burst at Nash Bog Pond, Percy quadrangle, Coos County, N.H. (loc. 19), in May 1969, have yielded significant new data on the two-till problem of New England. At the base of the Pleistocene section Carl Koteff and Fred Pessl, Jr., found a compact till with texture, structure, and color very similar to that of the lower till in southern New England. In places this till at Nash Stream is overlain by deltaic or lacustrine melt-water deposits. Where the till is not overlain by water-laid material, there is an oxidation profile about 20 feet deep, which is also characteristic of lower till elsewhere. The deltaic or lacustrine beds are overlain by as much as 100 feet of an upper sandy till; locally, at the base of the upper till, thrust structures oriented southward occur. The upper till is overlain by, and locally intertongues with, a cobble-to boulder-gravel outwash. At one locality the deltaic and lacustrine sediments which show extensive ice-collapse features are overlain and erosionally truncated by coarse outwash which shows no collapse. The interpretation is that the lower till and deltaic or lacustrine sediments are deposits of an earlier ice sheet, and the upper till and outwash are deposits of the last ice sheet to overrun New England.

<sup>15</sup> Leavitt, H. W., and Perkins, E. H., 1935, A survey of road materials and glacial geology of Maine; v. 2, Glacial geology of Maine: Maine Tech. Exper. Sta. Bull. 30, v. 2, 230 p.

Preliminary examination of the Nash Stream sections indicates the following generalized stratigraphy:

Colluvium	-----1 to 5 feet thick.
Upper outwash	--Chiefly glaciofluvial sand and gravel; exposed thickness 10 to 25 feet.
Upper till	-----Moderately compact to friable, sandy till; maximum exposed thickness 93 feet.
Lower outwash	--Chiefly deltaic sand, silt, and pebble gravel; maximum exposed thickness 75 feet.
Lower till	-----Moderate to very compact, sandy-silty till; locally oxidized to 20-foot depth; maximum exposed thickness 70 feet.

Two peat samples from the Nash Stream area have yielded radiocarbon dates of about 10,000 B.P. according to Meyer Rubin, and these dates are consistent with other bog dates in New England. Radiocarbon dates by Rubin of about 8,200 B.P. were obtained from fresh-looking logs found in till-like material near the dam at Nash Bog Pond. This is suggestive of either a hitherto unknown ice readvance at this time, or more likely, a till landslide that buried trees 8,200 years ago.

#### **Pleistocene stratigraphy, Cape Cod, Mass.**

All the important glacial units on inner Cape Cod occur in the Hyannis quadrangle (loc. 20). Here several major changes in the stratigraphic classification were made by R. N. Oldale. Restoration of preerosion and precollapse depositional surfaces on the outwash plains shows that the outwash can be divided into three major fans: the Mashpee pitted plain to the west, the Barnstable outwash plain in the Hyannis quadrangle, and the Harwich outwash plain to the east. The Mashpee and Barnstable plains are probably the same age and were deposited before the Sandwich moraine. Their ice-contact heads had been overrun by the Cape Cod Bay ice lobe and the sediments incorporated into the Sandwich moraine. The Harwich outwash plain is younger than the Sandwich moraine. Smaller glacial units include the oldest in the quadrangle—the Hyannis ice-contact deposits as well as the youngest glacial deposits—the lacustrine deposits that overlie the Sandwich moraine and the Harwich outwash deposits along the shore of Cape Cod Bay.

To the east in the Dennis quadrangle, interpretation of mapping shows that the Cape Cod Bay lobe retreated about 1 to 2 miles and changed from an active to a stagnant ice front between the time of deposition of the Sandwich moraine and that of the Harwich outwash plain.

Interpretation of mapping of Sandy Neck, a large spit that separates the Barnstable marsh from Cape Cod Bay, suggests that the growth of the spit has been mostly eastward with little advance of the beach and dune deposits southward over the marsh. Dune crests on the eastern part of the spit appear to represent

previous positions of the recurved distal end of the spit. The westernmost dune crest in this area appears to mark the position of the distal end of the spit about 2,500 years ago.

#### **Postglacial wind direction, Northfield, Mass.**

Transverse sand dunes and wind-eroded cusps and grooves on bedrock noted by J. H. Hartshorn near Northfield, Mass., indicate an early postglacial wind direction from the west-northwest.

#### **Readvance of ice margin, Mount Tom, Mass.**

Readvance of a retreating ice margin in central Massachusetts is documented, according to F. D. Larsen, by evidence over a north-south distance of 3 miles in the southeast corner of the Mount Tom quadrangle, Massachusetts (loc. 21). Exposures where till (11-feet maximum) overlies outwash or lacustrine sand are numerous. One exposure has the sequence sand-till-sand-till-sand. The till has crude stratification and grades from reddish-gray lodgement till to gray "till equivalent," that is, glacially redeposited lacustrine silts and clays. This would be expected if the ice margin readvanced or pulsated in a lake such as glacial Lake Hitchcock, the shore of which followed the northward retreating ice margin. The most convincing evidence for readvance is in an exposure 50 feet long and 12 feet high where lacustrine sediments have been overturned and thrust faulted to the south. Here, an envelope of gray varves and olive lacustrine sands surrounds a core of reddish-brown till, all of which are truncated at the base and thrust over brown lacustrine sands. The sequence gray varves—olive sand reappears in an auger hole 7 feet below the thrust fault.

#### **Level of Lake Hitchcock, Northfield, Mass.**

Deltas mapped by J. H. Hartshorn in the Northfield quadrangle, Massachusetts (loc. 22), some of which have been modified by recent erosion, have the topset-foreset contact at about 370 feet, indicating the level of Lake Hitchcock for most of its existence. Minor beach and (or) spit deposits at 340 feet indicate a lower lake level of shorter duration. The postglacial Connecticut River has flowed at altitudes as much as 320 feet above sea level in the north part of the quadrangle.

#### **Deglaciation in the Housatonic highlands, Connecticut**

In the Kent and Ellsworth quadrangles, Connecticut (loc. 23), deglaciation was primarily influenced by the Housatonic highlands, according to G. C. Kelley. These highlands, west of the Housatonic River valley, trend northeast and form a broad ridge having altitudes exceeding 1,500 feet. Late Wisconsin ice from the Hudson River valley entered this area of Connecticut

from the northwest by overtopping the highlands. During deglaciation the topographic influence of this ridge became dominant as downwasting resulted in a general restriction of ice flow over the ridge. Ice on the northwest side of this ridge appears to have remained active, whereas the widespread stranding and stagnation of ice to the southeast precluded the development of recessional moraines in large areas of western Connecticut. In the Housatonic River valley the nature of the glacial deposits indicate that stagnant ice persisted throughout deglaciation. Some active ice entered the Housatonic River valley in the form of minor ice tongues extending through the cols in the Housatonic highlands; at times it was superimposed on the stagnant ice. Recessional features were produced by these active ice tongues. Differential melting, variations in topographic relief, and extension of ice tongues caused minor ponding, frequent changes in fluvial drainage patterns, and the fluvial reworking of the limited glacial materials.

#### **Preglacial diversion of the Housatonic River**

In mapping the surficial geology of the Cornwall quadrangle, Litchfield County, Conn. (loc. 24), C. R. Warren found evidence of the pre-Wisconsin glaciation. About 0.2 mile below the covered bridge at West Cornwall the Housatonic River turns abruptly, abandoning a relatively open valley to enter a narrow rock gorge. This turn is caused by glacial till that blocks the preglacial valley. Because the river has had time to cut a gorge 140 feet deep into hard bedrock, the diversion must have taken place earlier than the Wisconsin Glaciation. Thus the till that caused the diversion must be Illinoian or older. The till appears to be the lower till of Pessl and Schafer<sup>16</sup> and, if so, may provide a key for dating the lower till and older deposit. For example, thick till at Dean Hill, northeast of Cornwall Bridge, that apparently dammed and ponded Furnace Brook is probably lower till; if the dating is Illinoian, lake clays that underlie gravel at Cornwall village may be of Sangamon age. Very little has been known hitherto about the pre-Wisconsin glacial history of inland parts of New England.

#### **Two tills in the Naugatuck Valley, Conn.**

The two stratigraphically distinct tills in the Naugatuck Valley area of western Connecticut (loc. 25) have previously been explained as deposits either of two successive ice sheets or of a single ice sheet. Structural phenomena along the contact of the two tills support

the interpretation that the tills are deposits of separate ice sheets, according to J. P. Schafer.<sup>17</sup> The weathered zone at the top of the lower till is truncated by erosion, and inclusions of lower till occur in the upper till. Drag and thrust features indicate a generally south and southeast transport direction, as do striae and other directional indicators.

#### **Karst in western Massachusetts and Connecticut**

W. S. Newman found karst features along the marble belts of northwestern Connecticut and western Massachusetts. Karst topography was probably quite extensive in the preglacial landscape, but undoubtedly has been much modified by erosion and burial during Pleistocene glaciation. Bedrock thalweg reversals undoubtedly reflect karst development prior to glaciation.

### **APPALACHIAN HIGHLANDS AND THE COASTAL PLAINS**

#### **APPALACHIAN PLATEAUS AND THE VALLEY AND RIDGE PROVINCES**

##### **Stratigraphic and paleoenvironmental studies of Paleozoic rocks**

Studies by J. B. Roen of over 1,000 drill-hole records and surface data from Belmont County, Ohio, southwestern Pennsylvania, and adjacent parts of West Virginia indicate that the subdivision of units and the nomenclature devised by Berryhill and Swanson<sup>18</sup> for the Monongahela and Dunkard Groups of Late Pennsylvanian and Early Permian age, Washington County, Pa., is valid there. Drill-hole records and surface data indicate a possible northern source area for the Dunkard basin in addition to previously postulated sources to the south. These same studies have shown that the upper limestone member of the Washington Formation of Permian age in Pennsylvania is not the same age as the upper limestone member in Ohio. The upper limestone member in its type area at Washington, Pa. (locality 1, index map), can be correlated with the Dilles Bottom Limestone Member of Greene Formation of Berryhill<sup>19</sup> in Belmont County, Ohio, which is some 80 feet above the upper limestone member of the Washington Formation in Ohio.

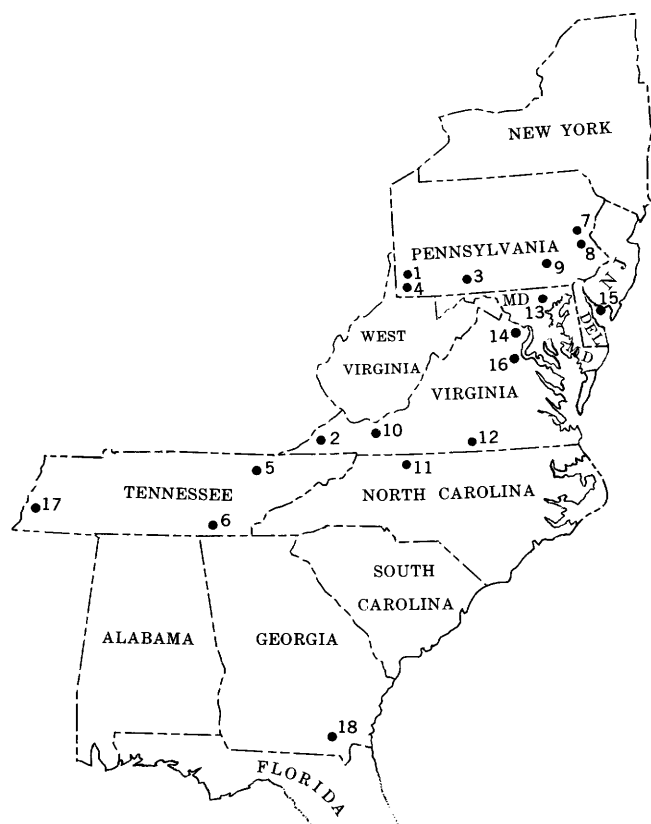
The upper limestone member of the Washington Formation, a key marker bed between the Washington and Greene Formations, grades southeastward into

<sup>16</sup> Pessl, Fred, Jr., and Schafer, J. P., 1968, Two-till problem in Naugatuck-Torrington area, western Connecticut, Trip B-1 in Guidebook for fieldtrips in Connecticut—New England Intercollegiate Geol. Conf., 60th Ann. Mtg., New Haven, Conn., 1968: Connecticut Geol. and Nat. History Survey Guidebook, 2, 25 p., paged separately, illus.

<sup>17</sup> Schafer, J. P., 1969, Structural relationships of tills in western Connecticut [abs.]: Geol. Soc. America Abstracts with Programs for 1969, North-Central Sect., pt. 6, p. 42.

<sup>18</sup> Berryhill, H. L., Jr., and Swanson, V. E., 1962, Revised stratigraphic nomenclature for Upper Pennsylvanian and Lower Permian rock, Washington County, Pennsylvania: Art 75 in U.S. Geol. Survey Prof. Paper 450-C, p. C43-C46.

<sup>19</sup> Berryhill, H. L., Jr., 1963, Geologic and coal resources of Belmont County, Ohio: U.S. Geol. Survey Prof. Paper 380, 113 p.



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clastic beds. The member, consisting of 20 to 30 feet of limestone near Washington, Pa., splits into two limestone beds that grade into sandstone, shale, and carbonaceous material southeast of Waynesburg, Pa. This facies change establishes a part of the southeast margin of a widespread fresh-to-brackish-water lake of Permian age in southeast Pennsylvania.

Formations of Pennsylvanian age in the southwest Virginia coal fields (loc. 2) were first named in 1893, but, with one exception, type sections had not been designated, nor had the formations been described or traced in detail. In a recent publication, R. L. Miller (r0249) redescribed the formations, designated and measured type sections, and redefined the boundaries of formations that have proved particularly difficult to identify and map.

A 45-foot bed of coarse-grained sandstone and disconformal quartz pebble conglomerate in the vicinity of Rockville, 1 mile west of Bard, Pa. (loc. 3), marks the base of the Foreknobs Formation of Dennison<sup>20</sup> of Late Devonian age in the western part of the Hyndman

quadrangle, Pennsylvania, according to Wallace de Witt, Jr. The conglomerate, apparently an offshore bar is the lateral equivalent of the conglomerate in the Jennings Formation of Flint<sup>21</sup> in southeastern Somerset County in the Berlin 15-minute quadrangle and is the "Lower Conglomerate" in the Chemung Formation of Stevenson.<sup>22</sup> The conglomerate at Rockville marks an abrupt change in deposition in the Upper Devonian rocks from fine-grained shale, mudrock, and siltstone below to coarse-grained sandstone, conglomerate, pebbly mudrock, and sandy siltstone above.

#### Resource potential of southwestern Pennsylvania limestone

The extensive clayey fresh-water limestone beds of Washington and Greene Counties, southwestern Pennsylvania (loc. 1), were evaluated by S. P. Schweinfurth for their potential as raw material for the manufacture of mineral wool and for use as a dusting material in the extensive local underground coal mines. The most promising limestone, the Benwood Limestone Bed of the Sewickley Member of the Pittsburgh Formation, is nearly, but not quite, wool rock quality. It would need blending with other raw materials, principally silica, to meet specifications. On the other hand, the limestones analyzed to date contain too much silica for use in coal-mine dusting. Adequate supplies of suitable raw material for mineral wool are available in the area in the form of blast-furnace slag so that the limestones are not needed at present for this purpose. Limestones for coal-mine dusting are now being brought into the area from a considerable distance.

#### Structural studies in the Appalachian Plateaus and Valley and Ridge provinces

Poor exposures of the many known small faults in the Appalachian Plateaus of southwestern Pennsylvania preclude delineation of their geometry; accordingly, their genesis and relation to gross structures of the plateau are unknown. In a recently excavated railroad cut at East View in the Waynesburg 7½-minute quadrangle, Greene County, Pa. (loc. 4), J. B. Roen found a low-angle thrust fault and associated wedging that strike parallel to the axial trends of the low-amplitude, open regional folds. The fault, located low on the northwest flank of the Bellevernon anticline, dips 28° NW. into the trough of the Waynesburg syncline. The fault is interpreted as the result of shortening accompanying low-amplitude flexural-slip folding. Beds in the synclinal trough were thrust upward onto

<sup>20</sup> Dennison, J. M., 1970, Stratigraphic divisions of Upper Devonian Greenland Gap Group ("Chemung Formation") along the Allegheny Front in West Virginia, Maryland, and Highland County, Virginia: *Southeastern Geology*, v. 12, no. 1, p. 53-83.

<sup>21</sup> Flint, N. K., 1965, Geology and mineral resources of southern Somerset County, Pennsylvania; *Pennsylvania Geol. Survey County Rept. C-56A*, 267 p.

<sup>22</sup> Stevenson, J. J., 1882, The geology of Bedford and Fulton Counties Pennsylvania: *Pennsylvania 2d Geol. Survey Rept. T-2*, 383 p.



the adjoining flank of the anticline. This type of thrust and wedging is generally associated with tightly folded strata and has not been described in areas of low-amplitude folding in the Appalachian Plateaus.

In the Valley and Ridge province of eastern Tennessee (loc. 5), the Cross Mountain wrench fault offsets major thrust faults about one-half mile and appears to coincide with a more extensive subsurface fault that is older in part. Analysis of aeromagnetic data by L. D. Harris suggests that major right-lateral displacement along the older subsurface part of the Cross Mountain fault has offset magnetic anomalies in the basement about 30 miles. This fault may have been active since Precambrian time. From the pattern of magnetic anomalies, the older subsurface part of the Cross Mountain fault is inferred to extend from central Kentucky through the Valley and Ridge and the Piedmont to the Atlantic Coastal Plain.

A study of drill cores, foundation excavations, and lakeshore exposures at the Sequoyah Nuclear Test Site, Tenn. (loc. 6), by R. A. Laurence and L. D. Harris and Tennessee Valley Authority geologists J. M. Kellberg, H. C. Harrill, and R. M. Allen, shows that the Kingston and Missionary Ridge thrust faults are one and the same, with the trace lying well to the west of the site instead of passing through it as shown on recently published maps. Limestone of Middle Ordovician age is exposed beneath the thrust fault, at least as far northward as the southern part of the Soddy Island quadrangle. The fault previously mapped as the Kingsport fault near Harrison, Tenn., does not extend northward to the test site area.

#### **Taconic belt and Reading prong**

J. B. Epstein reports that graptolites from the Pen Argyl Member of the Martinsburg Formation near its contact with the Shawangunk Formation at Lehigh Gap, Pa. (loc. 7), have been correlated with Zone 13 (Marathon, Tex., sequence) by W. B. N. Berry (University of California at Berkeley). This suggests that the Taconic hiatus in eastern Pennsylvania represents all of Late Ordovician time. It also suggests that a major structural break exists between rocks in the slate belt of eastern Pennsylvania and rocks immediately to the west, which have slightly younger paleontologic ages.

Previously unknown Martinsburg Formation in the Saucon Valley near Lanark, Pa. (loc. 8), lies in the hinge of a recumbent antiformal fold, according to A. A. Drake, Jr. The Martinsburg is overlain on the east by the older Jacksonburg Limestone and is in thrust contact with the Epler Formation (Beekmantown Group) on the west. Less than 2 miles along strike to

the west at Limeport, Pa., the Martinsburg overlies Allentown Dolomite (Upper Cambrian). This exposure, as well as the patchy distribution of Jacksonburg Limestone in the Great Valley between the Lehigh and Schuylkill Rivers, has led previous workers to postulate pre-Martinsburg folding and the subsequent development of a regional unconformity upon these beveled folds. Other workers have modified this concept slightly, believing that the folding was a broad regional arching developed after earliest Martinsburg deposition and that the unconformity formed during Martinsburg time. The new data demonstrate a normal stratigraphic sequence within the Saucon Valley without evidence of an unconformity. At the Limeport locality slaty cleavage is most nearly parallel to the Martinsburg-Allentown interface although this cleavage is folded and has closely spaced crenulations. Relict bedding has no systematic relation to the interface, which must be a tectonic contact. No evidence gained from detailed mapping to date supports a pre-Martinsburg (or post-earliest Martinsburg) folding event. The patchy distribution of Jacksonburg is more likely a result of tectonic complications, perhaps along the Stockertown fault (U.S. Geol. Survey, r0424, p. A28). Relations are further complicated by the mask of Taconic sequence rocks, including wildflysch, in the area.

Rocks of the Musconetcong nappe (U.S. Geol. Survey, r0424, p. A28) in the Saucon Valley, site of the Friedensville zinc mine, are restricted to the east edge of the valley and are separated from all other rocks to the east by the Black River fault, an apparent cross structure that is not understood completely at present. The south and west margins of the valley are framed by allochthonous Precambrian rocks which are thrust over inverted lower Paleozoic rocks mostly of the Beekmantown Group. These Precambrian and Paleozoic rocks are in fault contact with apparent right-side-up lower Paleozoic rocks that contain the zinc deposits. No aeromagnetic anomaly is evident at the mine site. The ore-bearing rocks are in steep fault contact with the allochthonous Precambrian rocks of South Mountain. South Mountain is a Musconetcong-type structure, as it has a paraconformable Paleozoic sequence along its north flank. Probably at least two tectonic units are present in the valley. The inverted lower Paleozoic rocks in the south part of the valley are probably in the lower limbs of the Musconetcong nappe. The thrust sheets may or may not belong to the large sheet which forms the core of the Musconetcong nappe to the east. South Mountain is probably the west extension of the Musconetcong nappe. The apparent right-side-up rocks may be the upper limb of the Musconetcong nappe dropped down, or they may be the



upper limb of the Lyon Station-Paulins Kill nappe brought up on a steep thrust. The lack of an aeromagnetic anomaly reflecting the core of either of these structures suggests, however, that an entirely different tectonic unit may be involved.

Beds of quartzite, arkose, feldspathic quartzite, quartz pebble conglomerate, dolomite-cemented impure sandstone, and a few thin beds of marble were mapped by A. A. Drake, Jr., well within the Precambrian terrane of the Reading prong in the Hellertown and Allentown East quadrangles, Pennsylvania (loc. 9). All these rocks have been previously called Hardyston Quartzite of Early Cambrian age. However, they do not have the petrographic aspect of the Hardyston, and they are more metamorphosed; moreover, individual units near the Precambrian-Paleozoic interface diverge from the interface. They are like many beds in the younger Precambrian sequence, previously known only from the Chestnut Hill-Marble Mountain massif to the east (U.S. Geol. Survey, r0424, p. A28). These quartzose rocks are the first rocks mapped to date that could have been a conceivable source for the Shawangunk Formation of Silurian age.

### THE BLUE RIDGE AND PIEDMONT

#### Structural relations in the Blue Ridge of Virginia

Reconnaissance mapping by D. W. Rankin in the Blue Ridge province of southwestern Virginia has shown that the Gossan Lead overthrust, the southeastern of two faults mapped by Stose and Stose<sup>23</sup> near Fries, Va. (loc. 10), is not a fault, but a nonconformity between the Ashe Formation (upper Precambrian) and the older Precambrian Cranberry Gneiss. The other fault, the Fries,<sup>24</sup> is a major overthrust. At Fries, the Cranberry overlies the Unicoi Formation (Lower Cambrian(?)). Three-quarters of a mile northwest of the fault, the Unicoi rests nonconformably upon Cranberry with no intervening upper Precambrian rocks. Thrusting of the Ashe Formation, whose thickness exceeds 10,000 feet, to juxtaposition with an unconformity representing the same interval implies many miles of transport.

Thirty miles southwest of Fries, two thick lithologically contrasting upper Precambrian formations, the Mount Rogers (D. W. Rankin and others, r0206) to the northwest and the Ashe to the southeast, are separated by a belt of Cranberry Gneiss 6 miles wide. The thickness of the Ashe, its lithologic contrast with

the Mount Rogers, and the narrowness of the Cranberry belt suggest that the Fries fault continues southwest within the belt of Cranberry Gneiss. The relationship of the southwestern continuation of the Fries fault to other major thrust faults is difficult to determine by reconnaissance mapping. The currently favored hypothesis is that the Fries merges with the Linville Falls fault which frames the Grandfather Mountain window. A similar fault would probably be present within the Cranberry Gneiss on the southwest side of the Grandfather Mountain window.

#### Studies in the Piedmont of North Carolina, Virginia, and Maryland

Near Winston-Salem in the North Carolina Piedmont (loc. 11), G. H. Espenshade and D. W. Rankin mapped a complex of gneissic granite, augen gneiss, biotite schist, and hornblende gneiss in a large dome, the Sauratown Mountains anticlinorium of Butler and Dunn,<sup>25</sup> over an area more than 40 miles long and as much as 15 miles wide, just northeast of the diverging end of the Brevard fault zone. Espenshade and Rankin (r1036) believe that these rocks correlate with older Precambrian rocks (Cranberry Gneiss and related rocks) in the Blue Ridge about 35 miles to the northwest. Fluorite-bearing granite within the complex is thought to correlate with chemically similar younger Precambrian granite of the Crossnore plutonic-volcanic group in the Blue Ridge which is characterized by peralkaline tendencies and much lower contents of barium and strontium and higher contents of niobium, yttrium, and fluorine than other granites in the region. The complex is overlain by biotite gneiss, schist, and amphibolite that appear identical to the Ashe Formation (upper Precambrian) of the Blue Ridge. Along the northern margin of the complex, garnet button schist and quartzite form the basal unit of rocks similar to those of the Ashe Formation. The contact is probably stratigraphic. If the correlations are correct, a major dome of Precambrian rocks is present in the Piedmont, comparable in size with segments of basement exposed in the Blue Ridge.

Quartzite forms the Sauratown Mountains along the axis of the dome, but relationships of this quartzite to gneiss and schist of the basement complex are obscure. The contrast in lithologies suggests that the quartzite was deposited on a beach or in shallow water during late Precambrian or Early Paleozoic time upon a high of Precambrian crystalline rocks. The domal structure is clearly Paleozoic but was perhaps inherited from the

<sup>23</sup> Stose, G. W., and Stose, J. J., 1957, *Geology and mineral resources of the Gossan Lead district and adjacent areas: Virginia Div. Mineral Resources Bull.* 72, 233 p.

<sup>24</sup> Rankin, D. W., 1969, The Fries fault—A major thrust in the Blue Ridge province of southwestern Virginia: *Geol. Soc. America Abstracts with Programs* 1969, pt. 4, p. 66–67.

<sup>25</sup> Butler, J. R., and Dunn, D. E., 1968, *Geology of the Sauratown Mountains anticlinorium and vicinity*, in *Guidebook for field excursions*, Geol. Soc. America, Southeastern Sec., Durham, N.C., April 1968: *Southeastern Geology Spec. Pub.* 1, p. 19–47.

older topographic high. The Sauratown Mountains anticlinorium appears to plunge southwestward beneath rocks of the Brevard zone and must be related in some way to the diverging end of the Brevard zone.

Structural studies by O. T. Tobisch and Lynn Glover III of rocks along the Carolina slate belt-Charlotte belt boundary in the Milton, Va.-N.C., area (loc. 12) reveal two generations of folding. The early folding involved several stages. Field relations and quantitative analysis of early folds indicate that folding began prior to metamorphism, largely by buckling. With the onset of metamorphism and the cleavage-forming process, new folds were formed and the pre-existing buckle folds were modified by compressive strain. During this event, a metamorphic gradient developed along the boundary of the two belts, and as the rocks became more ductile, a large antiformal nappe was formed in the Charlotte belt, rooted close to the boundary between the belts. Sillimanite-grade metamorphism in the Charlotte belt outlasted the early deformation, and some upwelling of material in this hot zone may have gently arched the nappe. Late post-metamorphism deformation produced two sets of late folds with different orientation, which appear to have a conjugate relationship, and probably formed contemporaneously. The relation between the Charlotte and Carolina slate belts may be analogous to the infrastructure-suprastructure relationship commonly found in other intensely deformed mountain belts of the world.

M. W. Higgins suggests that the Glenarm Series accumulated in a basin between the continent and an island arc. The remnants of the island arc are represented by the metavolcanic rocks of Cecil County, Md., the metavolcanic rocks beneath the Quantico and Arvonias Slates of Virginia, the slate belt rocks of Virginia, North Carolina, South Carolina, and Georgia (Little River Series of Peyton and Cofer<sup>26</sup>), and to the north the metavolcanic rocks in the Wilmington complex of Ward<sup>27</sup> of Delaware, and the Hartland Formation of New York.

#### Geophysical studies in the Maryland Piedmont

Interpretation of geophysical data from the Maryland Piedmont (loc. 13) by J. W. Allingham showed that the Mayfield gneiss dome is a shallow rootless, elongate nappe that developed from part of the Clarksville dome. Aeromagnetic information indicates that the northwestern boundary dips westward, and that its

southeastern boundary is almost vertical. Anomalously low radioactivity levels outline an elongate biotite, hornblende-rich zone, which is believed to be nonmagnetic pelitic schist of high metamorphic grade infolded near the crest of the Clarksville dome.

#### Malachite and specularite in Triassic rocks, Virginia

Malachite and azurite were found by P. M. Hanshaw in the Manassas Sandstone of Roberts<sup>28</sup> in the trench excavation for the Transcontinental Gas Pipeline Co. about 0.3 mile south along the pipeline from U.S. Route 50 about 1.2 miles east of Chantilly, Va. (loc. 14). Semiquantitative spectrographic analyses received in 1969 showed as much as 20,000 ppm Cu and 50 ppm Ag. A specularite-bearing conglomeratic sandstone with minor malachite occurs about 1 mile southeast of the copper locality. Studies of these deposits, were reported by J. P. D'Agostino and Hanshaw (p. C103-C106).

#### COASTAL PLAINS

##### Age of Chesapeake and Delaware Bays

Initial studies of the thick bay fills by J. P. Owens indicate a complex erosional and depositional history. In Delaware Bay (loc. 15) the fill in one channel system has an age beyond the limit of C<sup>14</sup> dating (> 38,000 radiocarbon years). A palynological analysis of the lowest beds (70 feet below mean sea level) by J. A. Wolfe indicates a climate as warm if not warmer than the present. Perhaps this fill is one of the first records of the warm conditions of the mid-Wisconsin interstadial. The fill also could be as old as the Sangamon interglacial age.

In Chesapeake Bay, wood from a depth of 108 feet below mean sea level yielded a C<sup>14</sup> age of 9,880 radiocarbon years. The age of this sample and the depth from which it was obtained fit the published sea-level curves.

##### Aquia Formation in northern Virginia

Detailed mapping in the Quantico 7½-minute quadrangle (loc. 16) by R. B. Mixon suggests that the upper part of the Aquia Formation (Paleocene) in that area was deposited in very shallow water near the edge of the depositional basin. This part of the Aquia is characterized by a low glauconite content, interstratified pebbly beds and clean lighter colored sands which locally are thin bedded, have heavy-mineral cross-lamination, and contain *Callianassa* borings. Toward the center of the basin, the type Aquia is a dark, massive, very fine to fine glauconite quartz sand containing considerable silt and abundant macrofossils. It prob-

<sup>26</sup> Peyton, A. L., and Cofer, H. E., Jr., 1950, Magruder and Chambers copper deposits, Lincoln and Wilkes Counties, Georgia: U.S. Bur. Mines Rept. Inv. 4665, 23 p.

<sup>27</sup> Ward, R. F., 1959, Petrology and metamorphism of the Wilmington complex, Delaware, Pennsylvania, and Maryland: Geol. Soc. America Bull., v. 70, no. 11, p. 1425-1458.

<sup>28</sup> Roberts, J. K., 1928, The geology of the Virginia Triassic: Virginia Geol. Survey Bull. 29, 205 p.

ably represents deposition in both near-shore gulf and inner shelf environments.

The facies change coincides with an abrupt thinning of the formation in a narrow northeast-southwest-trending zone. The zone is aligned with an apparent dislocation of the basement surface in the Quantico area (as interpreted from water-well logs at the Quantico Marine Base) suggesting that the change may be contemporaneous with faulting along the margin of the Salisbury basin.

#### Porters Creek Clay, Tennessee

Reexamination of the core samples from the U.S. Geological Survey Fort Pillow No. 1 well in Tennessee (loc. 17) by P. H. Tschudy disclosed a conspicuous facies change in the Porters Creek Clay. The lower part was laid down under distinctly marine conditions, the upper part nearer to shore, and the uppermost part yielded very little evidence of marine conditions. The formation thus represents a regressive sequence. The Porters Creek Clay was identified by its lithologic character as well as by its pollen content. It is underlain by the McNairy Sand and overlain by the Wilcox Group. Both formations have fossil suites that differ from the Porters Creek and serve to distinguish the formations.

#### Okefenokee Swamp, Georgia

A test hole on Trail Ridge, in southern Charlton County, Ga. (loc. 18), penetrated an impervious Pliocene clay at relatively shallow depths. According to S. M. Herrick, this impermeable clay together with similar clays occurring in the basal part of Trail Ridge is chiefly responsible for the existence of the Okefenokee Swamp.

## CENTRAL REGION AND GREAT PLAINS

### ARKANSAS

#### Geologic map of State

A revision of the State geological map, begun in 1968 as a cooperative venture with the Arkansas Geological Commission, is more than 40 percent completed. Two full-time geologists of the U. S. Geological Survey are working with from two to four geologists of the Geological Commission in the compilation of published and unpublished maps and reconnaissance mapping of areas that are unmapped or were mapped long ago. The revised map will be published at scale of 1:500,000.

#### Sand dunes west of Crowleys Ridge

While engaged in reconnaissance mapping for the State geologic map of Arkansas, B. R. Haley discovered sand dunes between the White River and



STATES IN CENTRAL REGION  
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Crowleys Ridge in a northeastward-trending, discontinuous belt from Woodruff County through Jackson, Craighead, Lawrence, Green, Randolph, and Clay Counties (locality 1, index map).

The dunes, partly dissected and destroyed, were deposited on a terrace that probably was the flood plain of the Mississippi River when it flowed west of Crowleys Ridge. Most dunes face northeastward and the others face eastward. The source of the sand and silt in these dunes may have been the ancient flood plains of the White, Current, and Black Rivers. Dunes are not present south or west of those streams.

### KENTUCKY

#### Geologic mapping of State

A cooperative project with the State begun in 1960 was more than 60 percent completed by May 1, 1970, when 346 geologic maps had been printed and another 60 maps approved for publication (fig. 1). Geologic mapping was in progress in more than 50 quadrangles. About 710 maps will be published to cover the 763 quadrangles (7½ minute) 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.

#### Geochemical criteria indicate sandstone in western Kentucky is Mississippian, not Pennsylvanian

An isolated block of sandstone lying on limestone of Late Mississippian age west of Princeton in western

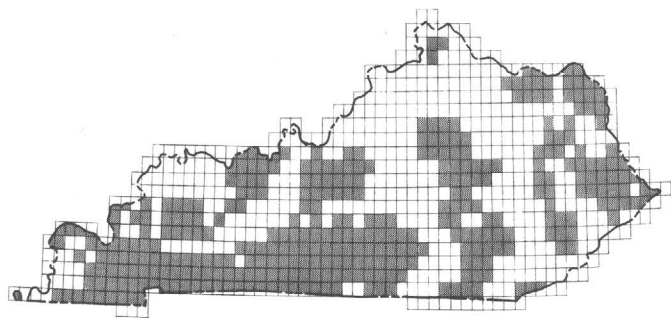


FIGURE 1.—Published geologic quadrangle maps of Kentucky as of May 1, 1970; small squares are 7½-minute quadrangles.

Kentucky (loc. 2) and mapped as the Caseyville Formation of Pennsylvanian age<sup>29</sup> is indicated by geochemical studies of J. J. Connor (p. D33–D35) to be more closely allied in chemical composition to sandstones of Mississippian age than to sandstone of Pennsylvanian age. The sandstone thus may be an erosional remnant of a channel fill of the Bethel Sandstone of the Chester Series as depicted by Reynolds and Vincent.<sup>30</sup>

#### **A lenticular sandstone of Late Mississippian age in northeastern Kentucky**

A sandstone in the Carter Caves area of northeastern Kentucky (loc. 3) that had been considered part of the Lee Formation and of Pennsylvanian age was found in 1962 to underlie marine strata with a Late Mississippian fauna.<sup>31</sup> Since then K. J. Englund has mapped the sandstone unit through the area where it is exposed.

The sandstone averages about 40 feet in thickness and 2 to 8 miles in width. It trends north-northeastward about 30 miles from Rowan County through Elliott and Carter Counties into Greenup County. The sandstone consists of fine to medium quartz grains and, locally, well-rounded quartz pebbles as much as half an inch in diameter. The lenticular body may have formed as an offshore bar. If there are similar sandstone bodies in the subsurface to the east, they may be oil and gas reservoirs.

#### **Nebraskan glaciation in northeastern Kentucky and southeastern Ohio**

A heretofore unrecognized advance from the northeast of the oldest recognized glaciation in North America, the Nebraskan, was reported by L. L. Ray (r0328). Deeply weathered drift of Nebraskan age caps a dis-

sected upland. Younger and less extensive drift of Kansan age was deposited in valleys cut below the level of the upland, indicating that the valleys were eroded in Aftonian time.

### **SOUTH DAKOTA**

#### **Paleozoic strait between Williston basin and mid-continent area**

An ancient strait, probably following a northwest-trending graben across the Siouxana arch in southern South Dakota (loc. 4), provided a marine connection between the Williston basin and the midcontinent area more or less continuously from Ordovician to Mississippian time. Study of recent well data by C. A. Sandberg indicates that Middle and Upper Ordovician and Lower Mississippian rocks are probably continuous between the Williston and North Kansas basins. Silurian and Devonian strata may have been continuous within this strait but largely removed during a short period of erosion during Early Mississippian time. Knowledge of the existence of the connecting seaway should be useful in making interregional correlations of early and middle Paleozoic marine faunas.

### **SOUTH DAKOTA AND WYOMING**

#### **Geophysical studies in the Black Hills**

Reconnaissance geophysical studies by M. D. Kleinkopf in the Black Hills show that the highest magnetic values of the region are in the Nemo district where positive anomalies of nearly 4,000 gammas in amplitude are produced by iron-formation and amphibolites. Gravity data over the core of the Black Hills indicate north-, northwest-, and northeast-trending structural alignments delineated by gradient zones. Major lithologic units such as Tertiary intrusives, amphibolite bodies, and the Harney Peak Granite mass are indicated by gravity anomalies of 5–15 mgals in amplitude.

### **MINNESOTA**

#### **Petrology of glacial deposits in the Mesabi Iron Range area**

Clay-mineral and heavy-mineral analyses were used by T. C. Winter to supplement field descriptions in an attempt to correlate a multitude of glacial-drift units in the Mesabi Range area (loc. 5). Some of the results indicate that clay in two tills at the surface is largely mixed layer (montmorillonite and illite), whereas clay in a deeply buried till is largely illite. No clay mineral predominates in several bouldery till units.

Two surficial tills have very few (generally <1 percent) heavy minerals in the sand fraction, the dominant types being pyroxenes and amphiboles. The sand frac-

<sup>29</sup> Sample, R. D., 1965, Geology of the Princeton West quadrangle, Kentucky: U.S. Geol. Survey Geol. Quad. Map GQ-385.

<sup>30</sup> Reynolds, D. W., and Vincent, J. K., 1967, Western Kentucky's Bethel channel—The largest continuous reservoir in the Illinois Basin: Kentucky Geol. Survey, Series X. Spec. Pub. 14, 19 p.

<sup>31</sup> Sheppard, R. A., and Dobrovolsky, Ernest, 1963, Mississippian-Pennsylvanian boundary in northeastern Kentucky: Art. 192 in U.S. Geol. Survey Prof. Paper 450-E, p. E45–E47.

tions of the bouldery tills contain about 2 to 3 percent heavy minerals. Pyroxenes and amphiboles generally predominate, but magnetite and limonite are dominant in some samples. The sand fraction of the deepest tills generally contains 2 to 3 percent heavy minerals, and magnetite and limonite are dominant in most samples.

## MICHIGAN

### Oronto Group (upper Keweenawan) of western Michigan

The upper Keweenawan rocks (Oronto Group) of western Michigan (loc. 6) are described by H. A. Hubbard as graywackes probably derived almost entirely from lower Keweenawan and older rocks. The Portage Lake Lava Series of middle Keweenawan age was previously assumed to be the source of the volcanic detritus of the upper Keweenawan rocks. The detritus includes few rock types that occur in the middle Keweenawan volcanic rocks except felsite, which occurs in both the lower and middle Keweenawan.

The Oronto rocks in Michigan are finer grained, less quartzose, and have smaller scale crossbedding than almost all the rocks Thwaites<sup>32</sup> assigned to the Oronto Group in Wisconsin. The rocks at Clinton Point, Wis., resemble the Oronto rocks of Michigan, and the attitudes suggest that a syncline and anticline parallel the shore of Lake Superior of western Michigan. The synclinal axis is within 2 miles of shore and the anticlinal axis is about 5 miles from shore, as interpreted by Thwaites but not by later writers.

### Pillow lavas in lower Keweenawan flows north of Marenisco

V. A. Trent found pillow structures while mapping lower Keweenawan lava flows north of Marenisco, Mich. (loc. 6). One pillow was wrapped in an argillaceous volcanic-clastic rock typical of the material the lavas were deposited on in the subaqueous environment.

### Volcanic rock in the Matchwood quadrangle, western Michigan

Geologic mapping of the Matchwood quadrangle (loc. 7) by R. F. Johnson shows that the volcanic pile identified in the Porcupine Mountain region by White and Wright<sup>33</sup> is later than, rather than part of, the Portage Lake Lava Series. Whether it interfingers with or unconformably underlies the Copper Harbor Conglomerate remains to be determined. The pile includes rhyolites and andesites and may have played a role in

the localization of copper deposits in the Nonesuch Shale.

### Upper Keweenawan rocks of western Michigan

Studies by W. F. Cannon along the south limb of the Marquette synclinorium in the Greenwood 7½-minute quadrangle (loc. 8) indicate that metasedimentary rocks of the Animikie Group (middle Precambrian) are in fault contact with lower Precambrian granitic gneisses across the entire quadrangle. Mylonitization and cataclastic deformation is common in the lower Precambrian gneisses near the faults and, although the stratigraphic base of the Animikie rocks is generally parallel to the faults, local truncation occurs where cross folds disrupt the regional trends in post-Animikie folds.

Detailed mapping of lower Precambrian rocks indicates the presence of two distinct fault blocks. Predominantly vertical movement of these blocks during post-Animikie deformation resulted in passive folding of the Animikie Group into the Marquette synclinorium. The outline of the fault blocks controlled the trend of the synclinorium.

### Kitchi and Mona Schists overlapped in Negaunee SW quadrangle

Mapping by D. W. Anderson, L. D. Clark, and R. V. Ingersoll in the Negaunee SW quadrangle (loc. 9) shows that the Kitchi and Mona Schists of lower Precambrian age are overlapped by a sequence of three units. These are a basal coarse-grained quartzite, a middle siltstone, and an upper magnetite-bearing inter-laminated siltstone, quartzite, and mudstone. Although the upper unit is not of economic grade, it has been traced as a magnetic anomaly across the quadrangle by W. P. Puffett. The Michigamme Slate overlies the three-unit sequence.

## SOUTHERN ROCKY MOUNTAINS

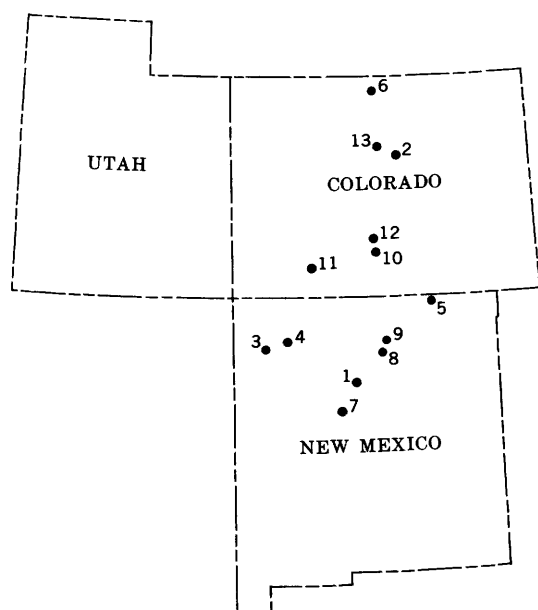
### MINERAL-RESOURCE STUDIES

#### Possible vein deposits near Santa Fe, N. Mex.

A gravity anomaly of possible economic significance was outlined by L. E. Cordell in the Cerrillos mining district, New Mexico (locality 1, index map), an area of generally small lead, zinc, copper, and gold vein deposits about 18 miles southwest of Santa Fe. The gravity anomaly has an amplitude of +13 mgals and a diameter of about 5.4 miles. The data suggest a shallow, possibly laccolithic, intrusive body about 5 miles in diameter underlying the area. Limestones occur at several levels within the sedimentary section, and there are scattered exposures of monzonitic intrusive rocks. The intersection of limestone beds with the possible

<sup>32</sup> Thwaites, F. T., 1912, Sandstones of the Wisconsin coast of Lake Superior: Wisconsin Geol. and Nat. History Survey Bull. 25, ser. 8, 117 p.

<sup>33</sup> White, W. S., and Wright, J. C., 1960, Lithofacies of the Copper Harbor conglomerate, northern Michigan: Art 3 in U.S. Geol. Survey Prof. Paper 400-B, p. B5-B8.



SOUTHERN ROCKY MOUNTAIN STATES

intrusive might be a locus of replacement mineralization, as is observed under similar circumstances in the Ortiz and San Pedro areas, about 12 miles to the south.

#### PRECAMBRIAN ROCKS IN COLORADO

##### Mineralogy of rutile- and topaz-bearing rocks, Colorado

Studies of rutile- and topaz-bearing Precambrian metamorphic rocks in the east-central Front Range, Colo. (loc. 2), by D. M. Sheridan and S. P. Marsh revealed other minerals not commonly reported in this region. Pink and gray corundum is locally abundant in rutile-bearing sillimanite-plagioclase gneiss. A bright-green chromium-bearing muscovite is locally conspicuous in rutile-bearing sillimanite-topaz-quartz gneiss. Gahnite, the zinc spinel, has now been found also in numerous exposures of partly altered rutile-bearing feldspar-quartz gneiss, some of which is sillimanitic, and in small pegmatite bodies along or near such gneiss; the mineral had been found earlier in cordierite-garnet-gedrite gneiss and locally in calc-silicate gneiss. Humite and clinohumite, not previously reported in this region, were found in a sequence of calc-silicate gneisses containing irregularly distributed gahnite, sphene, sphalerite, and galena.

#### MESOZOIC STRATIGRAPHY

##### Entrada and Wingate Sandstones in northwestern New Mexico

Preliminary study by M. W. Green of outcrops in the Wingate-Thoreau area, McKinley County, N. Mex. (loc. 3), suggests that the contact between the predominantly fluviatile medial silty member of the Entrada

Sandstone (Upper Jurassic) and the underlying Wingate Sandstone (Triassic) is gradational rather than marked by an unconformity or disconformity. No angular relationship is recognized between these formations nor is a sharp break evident in the sedimentary record at the top of the Wingate Sandstone. Instead, beds having lithologies typical of the two formations are interbedded at many places.

##### Morrison Formation in northwestern New Mexico

Siltstone lenses in the Brushy Basin Shale Member of the Morrison Formation near San Ysidro, N. Mex. (loc. 4), were found by E. S. Santos to contain up to 50 percent of the zeolite minerals clinoptilolite and analcime. This is the first reported occurrence of clinoptilolite in the Brushy Basin Shale Member; the only other occurrence of this mineral in rocks as old as Late Jurassic is from Oregon. The clinoptilolite is found only in reddish-brown siltstone, the analcime only in gray or greenish-gray siltstone. X-ray patterns of whole-rock samples showed no sign of either of these minerals in the claystone or mudstone of the member.

##### Palynologic studies in northern New Mexico

Palynologic data that show five correlation horizons between three sections, and indicate that palynologic differentiation coincides with lithologic boundaries between the Vermejo Formation (Upper Cretaceous) and the Raton Formation (Upper Cretaceous and Tertiary) were found by R. H. Tschudy in the Raton Basin, northern New Mexico (loc. 5). The three sections include two core sections and one surface section; one core included the lower 1,122 feet of the Raton Formation, and the other included 851 feet of the Raton and 14 feet of the Vermejo Formation. The surface section included all of the Vermejo Formation, 335 feet thick, and a sample from the underlying Trinidad Sandstone 30 feet below the contact. The Cretaceous-Tertiary boundary was found at 265 feet above the base of the Raton Formation in one core, and 288 feet above the base in the other.

#### STUDIES OF DRAINAGE CHANGES

##### Drainage history of the ancestral South Platte River, Colo.

An ancestral South Platte River probably first flowed from South Park eastward to Colorado Springs in Late Cretaceous time, according to G. R. Scott, R. B. Taylor, and R. C. Epis. By the Eocene it was forced west of Pikes Peak towards Canon City, possibly because of fault movements bringing up a large structural block including Pikes Peak. By late Eocene time a widespread flat surface had been cut over most of this area by several major streams. Parts of this surface



were buried by volcanic rocks in late Eocene and early Oligocene time, and early Oligocene lakebeds accumulated in blocked channels. Oligocene volcanic rocks of this age from the Thirtynine Mile volcanic field diverted the ancestral South Platte River back into its older course eastward from South Park to Colorado Springs on the north side of Pikes Peak. This course may have been held until the middle Pliocene. By the late Pliocene, the river was dammed by uplift along its course; it overtopped a gentle divide southeast of the Puma Hills, and was diverted into a tributary of the North Fork of the South Platte River. This is its present course. In late Pliocene and Pleistocene time, the principal change was the entrenchment of the river by deep canyon cutting.

#### **Ancestral Poudre River valley, Colo.**

Gravel deposits, recognized by J. T. Abbott and W. A. Braddock, fill an ancient stream channel that extends from the west side of the Big Narrows quadrangle, Colorado (loc. 6), eastward for about 13 miles. The westernmost occurrence of this gravel is on the north wall of the Cache La Poudre River valley about 400 to 600 feet above the river. The line of gravel deposits diverges from the present course of the Poudre, crosses the drainage with the north fork of the Poudre, and extends into the Livermore embayment. These deposits apparently mark the channel of an ancestral Poudre River valley.

### **STRUCTURAL AND GEOPHYSICAL STUDIES**

#### **Precambrian geosyncline in New Mexico**

E. J. McKay reported a sequence about 70,000 feet thick of slightly metamorphosed volcanic and clastic sedimentary rocks of Precambrian age in the west-central Manzano Mountains, N. Mex. (loc. 7). The great thickness of the sequence had earlier been considered a result of duplication of units by thrust-faulting, but McKay found no evidence to support thrust-faulting of the required magnitude. The thickness of this depositional unit suggests, instead, that the Manzano Mountains are on the site of a Precambrian geosyncline.

#### **Late Pennsylvanian folding in New Mexico**

Unconformities between beds of the Madera Formation (Middle and Upper Pennsylvanian) and beds of the Sangre de Cristo Formation (Upper Pennsylvanian and Lower Permian) were recognized locally by R. B. Johnson near the south end of the Sangre de Cristo Mountains of north-central New Mexico (loc. 8). These unconformities give evidence of diastrophic folding in the region during Late Pennsylvanian time. Differential thinning of the strata of the upper part of the

Madera Formation by erosion and that of the lower beds of the Sangre de Cristo Formation by nondeposition is demonstrated at these unconformities. The Late Pennsylvanian folds are accentuated by later folds of probable early Tertiary age that are superposed on them.

#### **Oligocene faulting near Rio Grande Trough, New Mexico**

Faulting in the Ortiz Mountains, N. Mex. (loc. 9), is closely related to major fault zones along the eastern margin of the Rio Grande Trough. Indirect evidence indicates that this faulting began during Oligocene time. Mineralized shear zones are assumed to have been formed about the same time. The faulting has modified the Ortiz Mountain intrusion, and this factor along with some nearly vertical igneous contacts causes this intrusion to differ from the classic laccolithic form, according to G. O. Bachman.

#### **Aeromagnetic and gravity studies in Colorado**

Aeromagnetic data interpreted by M. D. Kleinkopf show a strong correlation of anomalies and gradient zones with known geologic features in a 4,300-sq-mi area covering the southern Front Range and the north end of the Wet and Sangre de Cristo Mountains in Colorado. The southwest boundary of the Pikes Peak batholith is marked by a 300-gamma gradient zone which passes through the Cripple Creek mining district. The Thirtynine Mile andesite volcanic center shows a negative anomaly. Many of the major faults, like that along the flanks of the Sangre de Cristo Mountains, are expressed as magnetic gradient zones. Cambrian intrusives of gabbro and nepheline syenite show closed magnetic anomalies at McClure Mountain, Democrat Creek, and Gem Park.

Gravity studies by Kleinkopf in the Silver Cliff mining district, Colorado (loc. 10), suggest that volcanic accumulations extend nearly continuously in a trough southeast to the Rosita Hills volcanic center. The thickest volcanic accumulation appears to be located just northeast of Westcliff and at the Silver Cliff airport. Seismic refraction work complemented the gravity data in locating the boundaries between the low-velocity volcanic rocks and Precambrian gneisses.

### **IGNEOUS ROCKS IN COLORADO**

#### **Another resurgent caldera in the San Juan Mountains**

As a result of reconnaissance mapping for the Durango 2° sheet (loc. 11), supplemented by more detailed petrologic and geochronologic studies, P. W. Lipman and T. A. Steven (p. C19-C29) recognized a large resurgent caldera near Platoro, in the southeastern part of the San Juan volcanic field. Platoro caldera is a composite collapse structure about 20 km in diam-

eter that formed as a result of ash-flow eruption of the Treasure Mountain Tuff (Oligocene). After initial eruptions and related subsidence, the core of the collapsed block was resurgently domed, and the marginal moat was then filled to overflowing by andesite lavas. Renewed ash-flow eruption resulted in further collapse in the northern part of the main caldera; no resurgence seems to be associated with this late caldera, but it was also filled by a thick accumulation of andesitic lavas. Genetically related quartz latitic dikes and granitic stocks, with associated porphyritic rhyodacitic to quartz latitic lavas, were emplaced repeatedly around margins of the late caldera, and associated hydrothermal alteration and local ore deposition took place in other mineralized areas at Stunner, Gilmore, Jasper, Crater Creek, and Cat Creek. These mineralized areas, which had previously appeared anomalous, are therefore comparable to other caldera-associated mineralization in the central and western San Juan Mountains.

#### **An albite syenite stock in the Wet Mountains**

Syenitic felsite dikes of Early Cambrian age cut Precambrian crystalline rocks in the Wet Mountains (loc. 12); in southernmost Fremont County these dikes are genetically related to an albite syenite stock. Both the dikes and the stock are anomalously radioactive, at 5 to 10 times background. The areal distribution of similar dikes mapped by Q. D. Singewald in southernmost Custer County suggests that another albite syenite stock is concealed there.

#### **Geochronology**

Studies of porphyritic quartz monzonite intrusives in the central Front Range (loc. 13) by C. E. Hedge, R. U. King, and R. B. Taylor indicate that much revision of the previously suggested porphyry sequence is required. The Montezuma stock and related porphyry dikes and plugs were emplaced about 39 m.y. ago, and the associated ores of the Montezuma, Georgetown, and Silver Plume districts are at least slightly younger. In contrast, the biotite quartz latite of the Central City district is slightly older than 60 m.y., and it is younger than the pyritic gold ores of this district. Not only are multiple centers of mineralization postulated for this part of the Colorado mineral belt, but a timespan of more than 20 m.y. is involved.

### **NORTHERN ROCKY MOUNTAINS**

#### **MINERAL-RESOURCE STUDIES**

##### **Possible extensions of silver deposits near Clayton, Idaho**

Geologic mapping by S. W. Hobbs and W. H. Hays led to recognition of a plate of quartzite thrust faulted

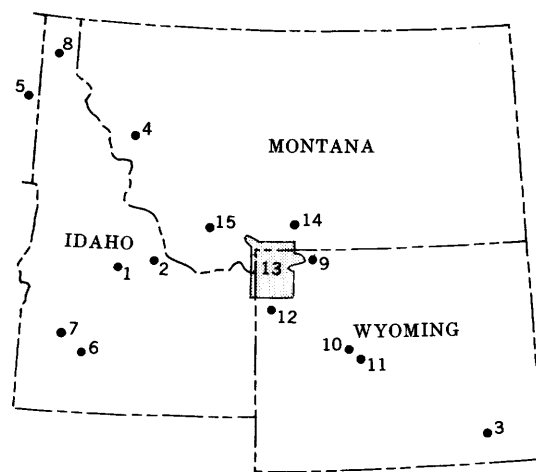
over the Ella Dolomite in Kinnikinic Creek near the Clayton Silver mine, Custer County, Idaho (locality 1, index map), and to the suggestion that possible new ore deposits might be found in the dolomite beneath the thrust fault. The dolomite extends northward beneath the thrust plate for an unknown but possibly considerable distance, and its relation to the thrust fault, and to later steeply dipping faults that locally are mineralized, suggests that the area of potential mineral deposits can be significantly extended.

#### **Geochemical investigations in the Gilmore district, Idaho**

Combined geologic, geochemical, and geophysical studies by E. T. Ruppel, K. C. Watts, and D. L. Peterson (r1942) in the northern part of the Gilmore (Texas) mining district, Lemhi County, Idaho (loc. 2), showed several lead-silver anomalies in an area mantled by glacial deposits and underlain by Jefferson Dolomite and a quartz diorite stock. The principal known ore bodies in the district are replacement veins in the lower and middle Jefferson near the margins of the stock, and the strongest geochemical anomalies are in the moraine above probable northward extensions of the main vein zone of the Gilmore district.

#### **Potential low-grade platinum deposits in Wyoming**

Northeast- and east-trending shear zones in the central part of the Medicine Bow Mountains, Wyo. (loc. 3), locally contain copper, gold, platinum, and palladium; the platinum-group metals are most abundant where intense shearing has involved mafic to ultramafic rocks. Geologic mapping in this area by M. E. McCallum shows that some of the shear zones are far more extensive than was previously known, and suggests that a much larger area should be examined for potential low-grade deposits of these metals.



NORTHERN ROCKY MOUNTAIN STATES



## WESTERN BELT BASIN

### Stratigraphic and structural data on Belt Supergroup

Rocks of the Belt Supergroup below the Missoula Group are widely exposed in the northern part of the Alberton quadrangle (loc. 4) west of Missoula, Mont., and geologic mapping there by J. D. Wells indicates that the formations have about the following thicknesses: Wallace, 10,000 feet; St. Regis, 3,800 feet; Revett, 1,700 feet; Burke, 8,800 feet; and Prichard, 7,000 feet. These rocks are folded into a series of north-west-trending asymmetric folds that locally are overturned and thrust to the northeast; the folds are poorly defined in the competent Wallace Formation. Cleavage, oriented nearly parallel to the axial plane, is common in the argillite units. The attitude of fold axes and of mineral streaking indicates that the direction of tectonic transport is to the northeast.

### Belt rocks near Spokane

Metamorphic rocks near Spokane, Wash. (loc. 5), range from schist and gneiss to only slightly metamorphosed sedimentary rocks. Geologic mapping by A. B. Griggs indicates that the metamorphic grade decreases to the southeast, and that the metamorphic rocks grade into Belt rocks in that direction. Most of the rocks near Spokane are correlated with the basal part of the Prichard Formation on lithologic and structural criteria; quartzite and siltite or carbonate-bearing rocks are believed to correlate with the central part of the Belt Supergroup.

## SNAKE RIVER PLAIN AND VICINITY

### Ancestral Snake River canyon potential source of ground water

Eruption of McKinney Basalt more than 30,000 years ago at a vent near Bliss, Idaho (loc. 6), caused the Snake River and its tributary, the Wood River, to change position, according to H. E. Malde. The basalt filled the canyon of the ancestral Wood River downstream to its junction with the Snake River Canyon of that time, 3 miles west of Bliss, thus diverting the Wood River to a southern course and impounding water to a depth of 500 feet in the Snake River Canyon upstream. Overflow of this water initiated cutting of the present Snake River Canyon west of Bliss, and the Wood River became entrenched in its new path at the edge of the McKinney Basalt. The lava-filled canyon formerly occupied by the Wood River, together with several miles of the filled ancestral Snake River Canyon downstream, is still concealed by McKinney Basalt and is a potential source for ground water.

### Lava tubes near Boise, Idaho

Pleistocene basalts along the South Fork Boise River (loc. 7) can be separated into several compositionally distinct flows separated by erosional intervals, according to K. A. Howard. The youngest flow, at Smith Prairie, contains a lava tube in a narrow tongue that followed an old creek channel. Several cubic kilometers of basalt passed through the tube and then cascaded into a Pleistocene river gorge, damming the river and forming alternating wedges of subaerial and foreset pillow basalts.

## STRUCTURAL AND GEOPHYSICAL STUDIES

### Purcell Trench a graben

Geologic and geophysical studies in the part of the Purcell Trench near Sandpoint, Idaho (loc. 8), suggest that the physiographic trench reflects a graben, as proposed by R. A. Daly almost 60 years ago. Geologic mapping by J. E. Harrison plus interpretation of gravity and aeromagnetic surveys by M. D. Kleinkopf combine to allow tracing of some rock units and faults between sparse bedrock outcrops in the glacial-filled trench. The graben, as well as the Selkirk Mountains that bound it on the west, is offset about 3 miles right laterally on the Hope fault and its several branches that fan out across the Purcell Trench. The graben apparently formed at the eastern edge of the Kootenai Arc mobile belt during intrusion of the Upper Cretaceous granodiorite that forms the core of the Selkirk Mountains. Offset of the graben and mountain range along the Hope fault system is early Tertiary as shown by K-Ar ages on porphyry dikes filling some faults in the system.

### Heart Mountain fault

Field observations by W. G. Pierce in the Beartooth Butte quadrangle, northwestern Wyoming (loc. 9), suggest that limited horizontal movement may have occurred on about one-third of the bedding-plane part of the Heart Mountain fault earlier than has been previously recognized. This early movement seems to have been separated from the later, more widespread, horizontal movement on the Heart Mountain fault plane by stream-channel deposition of the Crandall Conglomerate, the volcanic rocks of the Cathedral Cliffs Formation, and the Reef Creek faulting, in that order. Folding and high-angle faulting related to vertical movement in the basement occurred both before and after the main part of the Heart Mountain faulting, with about three fourths of the total vertical deformation taking place before the main part of the Heart Mountain faulting.

### Early Laramide deformation in Wyoming

Detailed correlation by W. R. Keefer of the complexly intertongued Frontier, Cody, and Mesaverde Formations (Upper Cretaceous) around the margins of the Wind River Basin (loc. 10) indicate that incipient troughs and uplifts developed in central Wyoming during the period immediately preceding the major phases of Laramide deformation.

Geologic mapping at Alkali Butte anticline, Wyoming (loc. 11), by M. W. Reynolds demonstrated that rocks earlier thought to be the Lance Formation<sup>34</sup> belong to the older Mesaverde Group. Strata of latest Cretaceous age are absent across the anticline, perhaps partly as a result of depositional thinning, but primarily as a result of erosion on the rising fold. Thinning of Paleocene beds across the anticline further demonstrates that the fold was growing in Paleocene time, but the pattern of thinning suggests that the ancestral fold crest was west of the present crest.

### GRAND TETON NATIONAL PARK AND VICINITY

#### Isotope ages of Precambrian crystalline rocks

Preliminary results of whole-rock Rb-Sr studies by J. C. Reed, Jr., and R. E. Zartman show that age of the oldest gneiss units in the Teton Range, Wyo. (loc. 12), fits a 2.73-b.y. isochron with an initial  $\text{Sr}^{87}/\text{Sr}^{86}$  value of about 0.7040. The date probably represents the date of high-grade regional metamorphism of the lower Precambrian basement—the rocks themselves may be considerably older.

#### New fossil discoveries

M. C. McKenna (American Museum of Natural History) and J. D. Love (p. D55-D61) found a tooth of *Leptoceratops*, a small hornless dinosaur, in the lower part of the type Pinyon Conglomerate, northwestern Wyoming. No fossils have previously been found in the type Pinyon, but 30 miles southeast the conglomerate is overlain and underlain by fine-grained strata containing Paleocene fossils. The *Leptoceratops* tooth was in place and is not abraded and so does not appear to have been reworked from older rocks. The type Pinyon overlies the type Harebell with a slight angular unconformity which increases to 90°, 3 miles southeast of the dinosaur locality. Either the orogeny that involved the Harebell and older rocks occurred within Late Cretaceous time or *Leptoceratops* survived into the Paleocene.

Love, McKenna, and C. C. Black (Carnegie Muse-

um) also found in the northern Jackson Hole area a complete skull and jaws of a Miocene oreodont, a rodent, and a rabbit that date about 1,000 feet of volcanic sandstone which extends nearly to the southern border of Yellowstone National Park. The rocks thus dated as Miocene overlie vertebrate-bearing pyroclastic rocks of early Oligocene age, and provide, for the first time, a clue to the history of Miocene volcanism and tectonism in the Yellowstone-Absaroka region and northern Jackson Hole.

#### Crustal instability near Jackson, Wyo.

A breccia of Quaternary age mapped by J. D. Love in the Jackson quadrangle, Wyoming, demonstrates the magnitude of local Quaternary tectonism and the crustal instability of the area near the town of Jackson. The breccia, a remnant of a preglacial talus several hundred feet thick, originally accumulated at the base of a west-facing steep mountain front underlain by Paleozoic sedimentary rocks, and intertongued westward with fossiliferous lacustrine sediments on the floor of Jackson Hole. Later in Quaternary time part of the deposit was downdropped 1,000 feet or more along the Hoback normal fault, and the downdropped block was rotated so that the coarsest facies now dips eastward into the fault and into the mountain front from which it was derived. The breccia and its structural relations thus also date part of the movement on the Hoback fault.

#### Glacial deposits in Yellowstone Park

Soil development in Yellowstone Park (loc. 13) was studied by K. L. Pierce as an aid in determining the age and correlation of glacial deposits. Soils on sandy rhyolitic deposits of Pinedale and late Bull Lake age display an A-C profile lacking development of structure or texture and having slight color modification. In contrast, soils on clayey calcareous till of Pinedale age show leaching, weak structure and weak color modification to a depth of 20 inches. Soils on clayey calcareous till of Bull Lake age show moderate structure and moderate color changes to a depth of 3 to 4 feet.

### IGNEOUS AND METAMORPHIC ROCKS

#### Granitic rocks in Stillwater Complex, Montana

N. J. Page and W. J. Nokleberg recognized a suite of granitic rocks along the base of the Stillwater Complex, Montana (loc. 14), between the complex and the gneisses in the Beartooth Mountains. Their mapping indicates emplacement of the rocks in the following order: (1) coarse-grained quartz monzonite of the

<sup>34</sup> Keefer, W. R., 1960, Progressive growth of anticlines during Late Cretaceous and Paleocene time in central Wyoming: Art. 105 in U.S. Geol. Survey Prof. Paper 400-B, p. B233-B236.

Mouat area, having a minimum age of 2.7 b.y.; (2) medium-grained quartz monzonite; (3) diorite; (4) fine-grained quartz monzonite, and (5) numerous apolites and contaminated aplite. The coarse- and medium-grained quartz monzonites contain inclusions of pyroxene hornfels and gabbro of the basal zone of the complex, and are therefore younger than the Stillwater Complex. Metamorphic foliation, which generally strikes east-west and dips steeply north, is present in the granitic rocks, in biotite schist pendants in the granitic rocks, and in the lower part of the Stillwater Complex. The original contacts between the Stillwater Complex and the granitic rocks are obscured by east-west-striking thrust faults and by younger, north-south-striking cross faults; both fault sets crosscut, and are therefore younger than, the metamorphic foliation. The granitic rocks are in fault contact with the meta-sedimentary gneisses to the south. Isotopic studies of the Stillwater Complex and adjacent rock must consider that after formation of the complex, the area was intruded by granitic rocks, penetratively deformed, recrystallized, and complexly faulted.

#### Precambrian crystalline rocks, Ruby Range, Mont.

A stratigraphic succession has tentatively been established by H. L. James for the Precambrian crystalline rocks of the Ruby Range, Mont. (loc. 15). The succession includes quartzite, dolomite that forms several major units, schist, amphibolite, and iron-formation. Amphiboles from both iron-formation and amphibolite show exsolution intergrowths of actinolite and cummingtonite. The initial amphibole probably was formed at a temperature in excess of 600°C. Mapping in this region indicates at least three periods of folding and at least two periods of metamorphism.

### BASIN AND RANGE REGION

#### Large salt dome of Cenozoic age discovered in Arizona

Regional geophysical studies by G. P. Eaton disclosed an elliptical salt dome  $5\frac{1}{2}$  miles long,  $2\frac{1}{2}$  miles wide, and extending to within 400 feet of the surface in the western Salt River valley, 17 miles west-northwest of Phoenix, Ariz. (locality 1, index map). This salt dome is unusual in that it occurs within an intermontane valley of the Basin and Range province and was emplaced in Cenozoic valley-fill sediments. A deep hole drilled on the northeast flank of the dome and bottoming in salt cut an anhydrite cap 90 feet thick and a section of salt more than 3,600 feet thick. Interpretation of gravity data suggests that maximum thickness of the dome is on the order of 8,000 feet.



STATES IN BASIN AND RANGE REGION

#### Altered (pyritized) rocks in San Simon Valley, southeastern Arizona

G. P. Eaton, during the course of gravity mapping of the San Simon Valley, Ariz. (loc. 17), recognized outcrops of altered (pyritized) rocks near the bedrock-gravel contact on the north flank of the Dos Cabezas Mountains in secs. 32, 33, and 34, T. 14 S., R. 28 E. The outcrops are in scattered bedrock highs that protrude from a pediment surface through gravels. The altered rock grades rapidly southward into fresh rock. Northward, however, the altered rock is covered by the gravel veneer on the pediment surface and perhaps the basin fill of the San Simon Valley.

Aeromagnetic and induced polarization anomalies, and mercury from air samples, are spatially associated with the altered area, which probably passes into an extensively pyritized body at depth. Copper minerals were not observed associated with any of the altered rocks.

#### Location of Bouse Formation extended

C. B. Bentley identified the Bouse Formation (Pliocene) in the Lake Mead National Recreational Area about 40 miles north of its previously known northernmost occurrence. The presence of the formation in this area is of geologic significance because it is a marine to brackish-water unit, and as such, it indicates the existence of a marine embayment prior to the establishment of the Colorado River drainage system. The formation is composed of a greenish-gray clay or a very light gray to white marl and a basal limestone 1 to 3 inches thick.

The Bouse unconformably overlies the pre-Colorado River alluvium along the banks of Lost Cabin Wash 2 to 3 miles east of Lake Mohave and about 12 miles north of Davis Dam. Outcrops are lenticular and discontinuous because of post-Bouse erosion, and the maximum known thickness of the unit in this area is about 30 feet.

#### **Marine strata of Late Triassic age in central Nevada**

The most easterly known outcrops of Upper Triassic marine strata in Nevada have been discovered in the Toiyabe Range, about 20 miles southwest of Cortez, in Lander County, Nev. (loc. 2). Fossils were collected in these rocks in 1968 by J. H. Stewart, and identified as Triassic in age by Mackenzie Gordon, Jr., in May 1969. In July 1969, J. R. MacMillan (Northwestern University) N. J. Silberling, and J. H. Stewart visited the locality and collected ammonites that were identified as trachyceratids of early Carnian (earliest Late Triassic) Age. The strata also contain an abundant fauna of brachiopods, gastropods, pelecypods, sponges, and bryozoans, some of which are silicified. The strata consist of light-gray limestone, some of which is bioclastic, and interstratified layers of chert pebble conglomerate. They are exposed for about 8 miles along the range. The total thickness of strata exposed is probably about 1,000 feet. The Triassic strata rest unconformably on chert, sandstone, and siltstone of the Pumpernickel and Havallah Formations of Pennsylvanian and Permian age.

#### **Age of intrusive rocks in western Pershing County, Nev.**

According to D. B. Tatlock and R. F. Marvin, biotite and hornblende pairs from six samples of granodiorite from the Trinity, Antelope, Shawave, Selenite, and Granite Ranges in western Pershing County, Nev. (loc. 3), have nearly concordant K-Ar ages of about 90 m.y. (Cretaceous). Biotite ages range from 85.1 to 93.7 m.y. ( $\pm 2.7$  m.y.), and hornblende ages, from 88.0 to 95.2 m.y. ( $\pm 9.1$  m.y.). Fission-track dating of sphene from two of the samples has further confirmed the approximately 90-m.y. age of the granodiorite. Exposures of the granodiorite aggregate more than 1,000 sq mi and display a relatively narrow compositional range, with silica content of 62 to 68 percent. Statistical treatment of major-element analyses shows that, for a given silica content, these rocks are virtually indistinguishable from granitic rocks of similar age in the eastern Sierra Nevada. In all probability, the granodiorite of western Pershing County is an eastern continuation of the Sierra Nevada batholith.

#### **Direction of movement of Roberts Mountains thrust fault determined in central Nevada**

Studies of numerous cylindrical, concentric, disharmonic folds in the upper plate of the Roberts Mountains thrust in the Shoshone Range, Nev. (loc. 4), by C. T. Wrucke, Jr., and at nearby Battle Mountain, by T. G. Theodore, document apparent tectonic transport toward the east-southeast and east, respectively, during the Antler orogeny. Fold axes, axial planes, and the statistical axis of folding of bedding planes in the Shoshone Range trend N. 21°–23° E., and the statistical axis of folding for bedding planes at Battle Mountain trends north-south. Abundant evidence for overturning of folds toward the east exists in both areas. These data imply thrust movements normal to the axial trends—east-southeast in the Shoshone Range, due east at Battle Mountain. Although data from other areas are needed for a thorough analysis of the movement plan of the upper plate of the thrust, the results are consistent with conclusions from regional stratigraphic studies, and they provide a more accurate determination of the thrust direction.

#### **Exploration target indicated by magnetic low in south-central Nevada**

A reexamination of the geology of the San Antonio Mountains, Nye County, Nev. (loc. 5), in conjunction with recently prepared aeromagnetic maps,<sup>35</sup> indicated a possible exploration area that is relatively untested. According to F. J. Kleinhampl, W. E. Davis, and J. I. Ziony, parts of the Tonopah and San Antonio mining districts are associated with magnetically anomalous areas. One magnetic low coincides in position and trend with major NNW-striking faults near the eastern edge of the Tonopah district. Bedrock associated with the low is mostly Tertiary andesitic rock like that at Tonopah. The rock is commonly altered, and at least one major mineralized prospect is associated with the low. Together these features indicate a target suitable for additional mineral exploration. The location of the target just north of and outside the main productive zone at Tonopah, but in an area underlain by similar rocks, is especially significant.

#### **Copper mineralization at Battle Mountain, Nev., dated as early Oligocene**

Potassium-argon radiometric ages of quartz diorite to quartz monzonite intrusive rocks at Battle Mountain, Nev. (loc. 6), range from 41.1 to 38.2 m.y., indicating intrusion during a relatively short period from late Eocene to early Oligocene time. Copper-gold-silver ore

<sup>35</sup> Davis, W. E., Kleinhampl, F. J., and Ziony, J. I., 1970, Aeromagnetic and generalized geologic map of the San Antonio Mountains, Nevada: U.S. Geol. Survey Geophys. Inv. Map GP-744. [In press]

being mined at Copper Canyon is spatially associated with the youngest and most siliceous of these intrusive bodies, a quartz monzonite stock dated at 38.2 to 38.5 m.y. Intrusion of the stock was closely followed by wallrock metallization, which is being studied by T. G. Theodore. The Copper Canyon deposit comprises two separate and petrologically distinct contact-metamorphic zones—an east ore body and a west ore body. The bulk of the early metallization in the east ore body occurs as disseminated pyrite, pyrrhotite, and chalcopyrite in a quartz-potassic feldspar-mica matrix of metamorphosed basal conglomerate of the Battle Formation (Middle Pennsylvanian). Apparently, some early pyrrhotite reacted with  $\text{CO}_2$  to form marcasite and siderite assemblages in the east ore body at the same time that late arsenopyrite-siderite-chalcopyrite veins were emplaced. Sulfides in the west ore body are mainly concentrated in the Pumpernickel Formation (Pennsylvanian(?)). Preliminary study indicates that ore-bearing skarns consist of hedenbergite-pyrite and grossularite-pyrrhotite assemblages—both with potassic feldspar and chalcopyrite.

#### **Late Devonian uplift in southeastern Nevada**

A major unconformity within the lower part of the Pilot Shale was found by C. A. Sandberg and F. G. Poole at Bactrian Mountain in the Pahrangat Range, Lincoln County, Nev. (loc. 7). This unconformity was located and precisely dated by closely spaced conodont samples through about 700 feet of strata. The magnitude of the time gap represented by the unconformity is indicated by the absence of eight Late Devonian (Famennian) conodont zones between beds only a few feet apart. This hiatus roughly corresponds to the hiatus during which the Roberts Mountains thrust was emplaced in the Carlin-Piñon Range area, and also with the development of the Cortez-Uinta arch of Famennian Age in east-central Nevada and west-central Utah.

#### **Mesozoic(?) klippen in central Nevada**

D. R. Shawe and F. G. Poole report that field relations and drill-hole information indicate that several outliers of Devonian carbonate rock in central Eureka County are klippen instead of windows in the Roberts Mountains overthrust as previously described.<sup>36</sup> For example, in the Roberts Mountains near Henderson Summit (loc. 8) and in the Sulphur Spring Range near the Old Whalen mine (loc. 9), two klippen consisting of Devonian eastern facies carbonate rock form prominent topographic ridges and overlie Ordovician west-

ern facies chert and shaly mudstone on low-angle faults. Regional geologic relations indicate that the klippen were probably emplaced during Mesozoic time (that is, between mid-Permian and mid-Tertiary) and, therefore, postdate emplacement of the Roberts Mountains thrust.

#### **Geochemistry of the Carlin, Nev., gold deposit**

A. S. Radtke (U.S. Geological Survey) and B. J. Scheiner (U.S. Bureau of Mines) reported that their studies of the fresh carbonate host rocks and the oxidized and unoxidized gold ores of the Carlin mine, Eureka County, Nev. (loc. 10), indicate that gold, quartz, barite, pyrite, and other sulfides were introduced into the Roberts Mountains Formation by acid hydrothermal solutions. Laboratory investigations of the carbonaceous materials in the host rocks and ores, and studies of reactions between carbonaceous materials and gold-bearing solutions also show that the rocks contain; (1) an activated carbon component capable of absorbing gold chloride or gold cyanide complexes from solution, (2) a mixture of high-molecular-weight hydrocarbons usually associated with the activated carbon components, and (3) an organic acid, similar to "humic acid." These components, when reacted with aurous chloride complexes, are believed to form stable gold chelates or other gold-organic compounds. Subsequent oxidation of the gold-organic compounds destroys the organic component and leads to the formation of metallic gold. Although most of the known gold ore at the Carlin mine is in the organic-rich Roberts Mountains Formation of Silurian age within several hundred feet below the Roberts Mountains thrust fault, similar organic compounds are also present in the underlying Devonian limestone and in carbonate and shale units in the Vinini Formation (Ordovician) in the upper plate of the Roberts Mountains thrust fault, and all three formations are now considered to be favorable host rocks for the deposition of gold.

#### **Multiple calderas in central Nevada**

Geologic mapping by E. B. Ekren, W. D. Quinlivan, and others in Hot Creek Valley, Big Sand Springs Valley, southern Pancake Range, and the Morey Peak area of the Hot Creek Range in central Nevada outlined an area (loc. 11) of volcanic subsidence about 40 miles long (north to south) and 30 miles wide (east to west). The area contains several nested and superimposed cauldrons, some of which overlap. Drilling has revealed that the largest and oldest of these is filled with at least 6,000 feet of quartz latitic ash-flow tuff. This tuff is strikingly similar to and virtually the same age as the uppermost part of the Windous Butte Tuff of

<sup>36</sup> Roberts, R. J., Montgomery, K. M., and Lehner, R. E. 1967, *Geology and mineral resources of Eureka County, Nevada*: Nevada Bur. Mines Bull. 64, 152 p.

Cook,<sup>37</sup> one of the most widespread ash-flow tuffs in the Great Basin, and one which is thickest and shows more lithologic variations adjacent to the cauldron complex of central Nevada than in any other locality. These data suggest that the earliest caldera resulted from the extrusions of the Windous Butte and was subsequently filled with 6,000 feet of quartz latitic tuff and thinner overlying units. The units that are younger than the quartz latitic tuff probably were entirely confined to the area of volcanic subsidence. Later eruptions of ash-flow tuff gave rise to smaller calderas several of which were sites of small lakes. Most of the vast complex has remained structurally and topographically low, but parts have resurged dramatically to form the rugged Morey Peak massif in the Hot Creek Range, and the Squaw Hills between Hot Creek Valley and Big Sand Springs Valley.

#### **Intense tectonic and igneous activity near Lake Mead, Nevada-Arizona**

Studies by R. E. Anderson have disclosed that within a 30-mile-wide deformed belt southwest of Lake Mead, Nevada-Arizona (loc. 12), numerous internally distended, platelike masses of Tertiary and Precambrian rocks are shifted over and past one another for distances of several miles on interrelated systems of transcurrent and décollementlike faults. Many miles of cumulative horizontal extensional strain is indicated by consistent displacement of younger rocks over older in a S. 70° W. direction. The intense distension suggests stretching and thinning of surficial rocks over zones of tensional rifting and pluton emplacement. Approximately 50 K-Ar ages on upper Tertiary volcanic and plutonic rocks are consistent with mapped relations that indicate contemporaneous volcanism, tectonism, and plutonism of intense magnitude and brief duration.

#### **Data from Eureka district, Nevada, on time of movement on Roberts Mountains thrust**

Geologic investigation by T. B. Nolan in the Eureka district, Nev. (loc. 13), resulted in a better understanding of the development of the Roberts Mountains thrust, a major geologic structure in central Nevada that crops out just west of the Eureka and Pinto Summit quadrangles. The Joana Limestone, of Early Mississippian age, and its adjoining formations, the Pilot Shale below and the Chainman Shale above, exhibit in the several facies exposed not only progressive changes in lithology but also several notable breaks in sedimentation. These indicate that the Roberts Mountains thrust was spasmodically active from later Devonian time to

the middle Mississippian, and that the orogeny that caused it was progressively less intense to the east.

#### **Lower Paleozoic rocks telescoped in Toquima Range, central Nevada**

Fossils identified by R. J. Ross, Jr., and collected by E. H. McKee in the Toquima Range, central Nevada (loc. 14), from the Antelope Valley Limestone (Ordovician) beneath the Tor Limestone (Devonian) in the June Canyon sequence of Kay and Crawford,<sup>38</sup> show that 400 to 1,000 feet of Ordovician and Silurian rocks are missing from the section. Only 1 mile to the east, however, in the Mill Canyon sequence of Kay and Crawford the full thickness of the Antelope Valley Limestone is overlain by the Roberts Mountains Formation (Silurian) beneath rocks of Devonian age. This striking difference in stratigraphy supports the concept that the two sequences now separated by a thrust must have been separated by a distance of several miles. Elsewhere in the Toquima Range, McKee has found similar juxtaposition of rocks from different areas.

#### **Geologic mapping of drill holes by electrical resistivity and gamma-ray intensity**

Electrical resistivity and gamma-ray intensity measurements made by C. J. Zablocki in a geologic drill hole in Iron Canyon, Lander County, Nev. (loc. 15), were demonstrated to be useful in placing descriptive boundaries in many sections of the hole where different rock types are interbedded. Organic carbon (graphite?) content as low as 3 percent in the predominantly chert section apparently renders the rock electronically conductive, which suggests continuity of the organic mineral, or material, in the rock framework.

#### **Direction of thrust movement determined from folds in Raft River Range, northwestern Utah**

Folds developed during metamorphism have now been examined by R. R. Compton over a large part of northwestern Utah (loc. 16) and adjoining Idaho. An older series of folds indicates widespread flowage in a broad arc convex toward the north and northeast. Post-metamorphic folds and thrusts indicate movement toward the northeast and east, but appreciable thrusting took place before or during metamorphism.

## **PACIFIC COAST REGION**

### **CALIFORNIA**

#### **Salton trough region**

R. V. Sharp began a regional mapping study of the Salton trough and adjacent mountain ranges, covering

<sup>37</sup> Cook, E. F., 1960, Great Basin ignimbrites [Nevada-Utah], in *Geology of east central Nevada: Intermountain Assoc. Petroleum Geologists, 11th Ann. Field Conf., 1960, Guidebook*, p. 134-141.

<sup>38</sup> Kay, Marshall, and Crawford, J. P., 1964, Paleozoic facies from the miogeosynclinal to the eugeosynclinal belt in thrust slices, central Nevada: *Geol. Soc. America Bull.*, v. 75, p. 425-454.

parts of San Bernardino, Riverside, San Diego, and Imperial Counties in southern California (locality 1, index map), a region that is traversed by several fault zones belonging to the San Andreas fault system. A geologic map at a scale of 1:125,000 will emphasize deformational features within this remarkably active region.

An acoustical profiling study of the Salton Sea, made in cooperation with the University of California at Riverside, provided the following information on the nature of deformation in the Cenozoic sediments underlying the axial part of the Salton Trough and its relationship to the San Andreas fault located along the northeast edge of the sea: (1) The sedimentary fill to depths of about 3,000 feet is nearly flat lying throughout most of the sea and has very slight synclinal curvature, the axis of which is parallel to the San Andreas fault and the Salton trough. (2) The sediments are broken by numerous steeply dipping faults, all apparently of small vertical separation and probably subparallel to the San Andreas fault, across the entire width of the sea at its northern and southern extrem-

ities. (3) Faulting is not evident to any marked degree in the north-central latitudes of the sea. (4) Vertical separation of reflectors across most of the breaks appears to diminish upward, so that the uppermost beds, as well as the sea bottom, show no vertical offset.

#### Lateral displacement on the Garlock fault

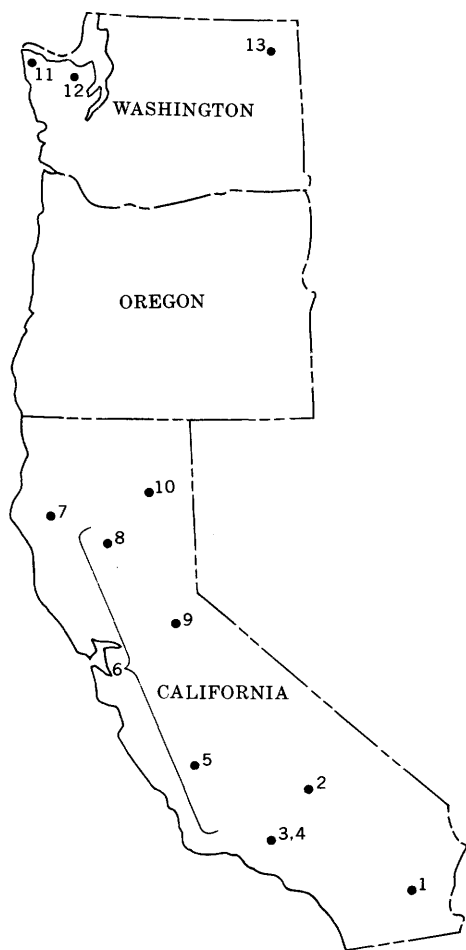
Pendants of similar eugeosynclinal metasedimentary rocks in upper Mesozoic plutons on opposite sides of the Garlock fault (loc. 2) provide evidence for left-lateral displacement on the fault, according to G. I. Smith and K. B. Ketner, and corroborate previous estimates of 30 to 40 miles displacement inferred from other evidence. The eugeosynclinal metasediments on the north side, in the El Paso Mountains, belong to the Garlock Formation, in part of Permian age; undated rocks on the south side, in Pilot Knob Valley, are comparable facies and consist largely of chert with lesser amounts of slate, quartzite, sandstone, sandy limestone, and stretched-chert conglomerate.

#### Late Pleistocene or Holocene folding in southern California

C. M. Wentworth, J. I. Ziony, and J. M. Buchanan identified a fold of probable late Pleistocene or possibly Holocene age along the south margin of the Repetto Hills, Los Angeles, Calif. (loc. 3). The sharp monoclinical fold is expressed at the surface as a rounded topographic escarpment as much as 75 feet high. Bedding in surficial gravels dips as much as 30° southward and is parallel to the ground surface. Stratigraphic relationships exposed in a deep excavation west of the Long Beach Freeway show that progressive folding took place concurrently with transport and deposition of the gravels.

#### Miocene stratigraphy in southern California

Complex geologic relationships in clastic Miocene rocks in the easternmost Santa Monica Mountains. (loc. 4) are most satisfactorily explained by abrupt facies changes rather than by previous interpretations of simple stratigraphy and complex structure.<sup>39</sup> C. M. Wentworth, J. M. Buchanan, and J. I. Ziony report that sandstone, conglomerate, and breccia of the Cahuenga Formation of Neuerberg<sup>39</sup> overlie sandstone and conglomerate of his Topanga Formation (middle Miocene) in Brush Canyon and grade laterally and upward into thin-bedded sandstone and shale of the Hollycrest Formation (middle Miocene) of Neuerberg<sup>39</sup> at the east side of Hollywood Reservoir. Farther



PACIFIC COAST STATES

<sup>39</sup> Neuerberg, G. J., 1953, Geology of the Griffith Park area, Los Angeles County, California: California Div. Mines and Geology, Spec. Rept. 33, 29 p.



west, near the Hollywood Freeway, the Cahuenga beds are absent, and the Hollycrest Formation directly overlies the Topanga Formation with a conformable contact. These relations require that the Cahuenga beds are middle Miocene rather than Cretaceous and remove the necessity for the numerous faults used by Neuerberg to juxtapose the Cahuenga beds and the Hollycrest Formation.

#### Faulting in coastal California

Geologic mapping by T. W. Dibblee, Jr., west of the San Andreas fault in San Luis Obispo and southern Monterey Counties (loc. 5) reveals that the "Nacimiento" fault, as heretofore mapped in the San Rafael wilderness area, extends northwest, not into the type Nacimiento fault near the Nacimiento River, but instead veers north-northwest directly into a major alignment locally called "Riconada", "San Marcos", "Espinoza", and "Reliz" faults. This fault alignment is within the Salinian block of crystalline basement, and is parallel to and about 20 miles southwest of the San Andreas fault. Severe drag folding in Tertiary sedimentary rocks traversed by this faultline indicates that much if not all the movement was right lateral, as on the San Andreas fault.

#### Underthrusting of Franciscan rocks

E. H. Bailey, M. C. Blake, Jr., and D. L. Jones (p. C70-C81) have concluded that the belt of serpentinite that underlies sedimentary rocks of the Great Valley sequence throughout the California Coast Ranges (loc. 6) is the basal part of an ophiolite sequence which they interpret as oceanic crust on which the Great Valley sequence was deposited. Mudstone of the Knoxville Formation of Late Jurassic (Tithonian) age, the oldest sedimentary rock of the Great Valley sequence, in most places depositionally overlies a typical ophiolite sequence that extends downward through local impure chert, pillow lava and breccia, mafic rocks, and basal serpentinitized ultramafics. A great boundary fault, the Coast Range thrust, separates the ophiolites and the Great Valley sequence from underlying Franciscan rocks which have been underthrust eastward as a result of sea floor spreading. Beneath the Coast Range thrust, the Franciscan rocks are highly deformed and converted to blueschists in an inverted sequence. Above the thrust, the serpentine is highly sheared in some places, but other rocks of the ophiolite sequence are little sheared and are metamorphosed only to the extent of containing zeolite minerals and epidote.

Evidence substantiating the concept that eugeosynclinal Franciscan rocks are thrust many miles eastward beneath an upper plate of Klamath continental crust

was found by W. P. Irwin and D. L. Jones in northern California. Lower Cretaceous sedimentary rocks on Rattlesnake Creek in Pickett Peak quadrangle (loc. 7) consist of 2,000 feet of conglomerate, sandstone, and shale resting unconformably on Paleozoic rocks of the Klamath Mountains. The lower part of the Cretaceous sequence includes nonmarine beds that contain abundant plant and unionid molluscan fossils. The upper part includes marine strata of Hauterivian Age. The plant-bearing beds are correlative with beds elsewhere in the Klamath Mountains that contain similar floras known to be of Valanginian Age. The beds on Rattlesnake Creek contrast markedly with eugeosynclinal Franciscan rocks that are nearly equivalent in age and that are widely exposed scarcely 10 miles to the southwest. There the Franciscan rocks contain abundant fossils (*Buchia*), ranging in age from Late Jurassic (Tithonian) to Early Cretaceous (Valanginian). The Franciscan rocks are greatly deformed, slightly metamorphosed, and are thought to be deposited on oceanic crust. The close proximity of rocks of these two radically contrasting facies demands horizontal transport on a large scale.

#### Geophysical studies, northern Sacramento Valley

Geophysical studies by Andrew Griscom indicate a circular gravity low 20 miles in diameter with an amplitude of about 25 mgal centered 15 miles west of Red Bluff (loc. 8). This low appears to be caused by a thick section of Cretaceous sedimentary rocks. If the density contrast between these sedimentary rocks and the underlying basement rocks averages about 0.1 g/cm<sup>3</sup>, then the gravity data imply a Cretaceous stratigraphic section at least 20,000 feet thick.

Gravity data obtained by Griscom, and aeromagnetic data also indicate that the ultramafic rocks associated with the Trinity thrust fault of the eastern Klamath region extend southeastward under the Cretaceous and Tertiary sedimentary and volcanic rocks at the north end of the Sacramento Valley and probably connect with the westernmost faults of the Foothills fault system in the western Sierra Nevada where they disappear under the volcanic rocks 20 miles due north of Oroville. G. A. Davis<sup>40</sup> postulated connection of the Trinity thrust fault with the Melones fault of the Foothills fault system, but the geophysical data do not appear to support this correlation.

#### Upper Jurassic stratigraphy revised in Sierran foothills

Geologic mapping in Amador County, Calif. (loc. 9), by R. V. Sharp and W. A. Duffield demonstrated that

<sup>40</sup> Davis, G. A., 1969, Tectonic correlations, Klamath Mountains and western Sierra Nevada, California: Geol. Soc. America Bull., v. 80, p. 1095-1108.

the upper part of the Cosumnes Formation at its type locality on the Cosumnes River is a lateral variant of the Logtown Ridge Formation, a sequence of metavolcanic rocks. Southward from the Cosumnes River, the Logtown Ridge Formation is continuous along strike with the volcanic Brower Creek Volcanic Member of the Mariposa Formation, previously believed by L. D. Clark<sup>41</sup> to be on the west limb of a regional syncline in the Mokelumne River section and to overlap the Logtown Ridge Formation. Slate of the overlying Mariposa Formation, shown by Clark<sup>41</sup> in the core of the same fold and terminating north of the Mokelumne River, is now known to be continuous northward at least as far as the Cosumnes River. Unnamed bedded metavolcanic rocks east of the Mariposa Slate in Amador County are laterally equivalent to the Brower Creek Volcanic Member of the Mariposa Formation, again shown by Clark<sup>41</sup> to be on the eastern limb of the same syncline at the Mokelumne River. The synclinal structure cannot be recognized in Amador County.

#### **Cenozoic volcanic rocks in northeastern California**

Cenozoic rocks at the south end of the Cascade Range north of Mount Lassen (loc. 10) are being mapped by G. A. MacDonald. Uppermost Pliocene(?) andesites unconformably overlie the Tuscan Formation and its Nomlaki Tuff Member of very late Pliocene age along the east side of the Sacramento Valley. The Tuscan Formation is unconformable on the nonmarine Montgomery Creek Formation (Eocene) which overlies the marine Chico Formation (Cretaceous). The uppermost Pliocene(?) andesites are overlain by a series of volcanic rocks ranging in composition from basalt to dacite and in age from Pleistocene to Holocene. The upper Pliocene(?) volcanic rocks are folded along nearly east-west axes and are block faulted. Faulting continued through the early Pleistocene, but ceased before late Pleistocene.

### **WASHINGTON**

#### **Pre-Tertiary rocks in northwest Washington**

The only known pre-Tertiary rocks west of the Cascade Mountains and north of the Klamath Mountains were found by P. D. Snavely, Jr., and N. S. MacLeod at Point of Arches (loc. 11) during reconnaissance mapping of the Olympic coast of Washington. A small hornblende diorite stock, (about 1 mile wide) intrudes quartzite, chert, graywacke, argillite, and pillow basalt, and is overlain by more than 200 feet of well-bedded marine sedimentary breccia of late Eocene age.

<sup>41</sup> Clark, L. D., 1964, Stratigraphy and structure of part of the western Sierra Nevada metamorphic belt, California: U.S. Geol. Survey, Prof. Paper 410, 70 p.

The breccia, which contains clasts of the pre-Tertiary rocks, crops out intermittently as far north as Cape Flattery where it is more than 1,500 feet thick. The diorite in most places has a protoclastic texture and has been recrystallized; pegmatite, aplite, and quartz veinlets are common. The pre-Tertiary sedimentary and igneous rocks at Point of Arches are the only known pre-Tertiary rocks in Washington west of the Puget trough.

#### **Olympic Mountains**

Continuing field studies by W. M. Cady, R. W. Tabor, and R. S. Yeats in the Olympic Peninsula, Wash. (loc. 12), show that the eastern Olympic Mountains are composed of several fault-bounded volcanic-sedimentary lithic assemblages of early Eocene or possibly Paleocene to early Miocene age. The assemblages are arcuate and concentric, highly folded, but predominantly overturned away from the central part of the mountains.

The outermost assemblage contains chiefly basaltic volcanic rocks (Crescent Formation) whose compositions are typical of oceanic ridge tholeiite, as shown by the percentages of K<sub>2</sub>O (< 0.5), TiO<sub>2</sub> (< 1.5) and P<sub>2</sub>O<sub>5</sub> (< 0.2), by 2 to 3 percent total Na<sub>2</sub>O and K<sub>2</sub>O in rocks having 47 to 50 percent SiO<sub>2</sub>, and by the ratio Fe<sub>2</sub>O<sub>3</sub>/FeO (commonly < 0.5).

Probable vents are buried in the Puget Sound-Juan de Fuca Strait areas, and the volcanic rocks once thinned southwestward from them. The basaltic rocks are 10 miles thick at the eastern margin of the peninsula.

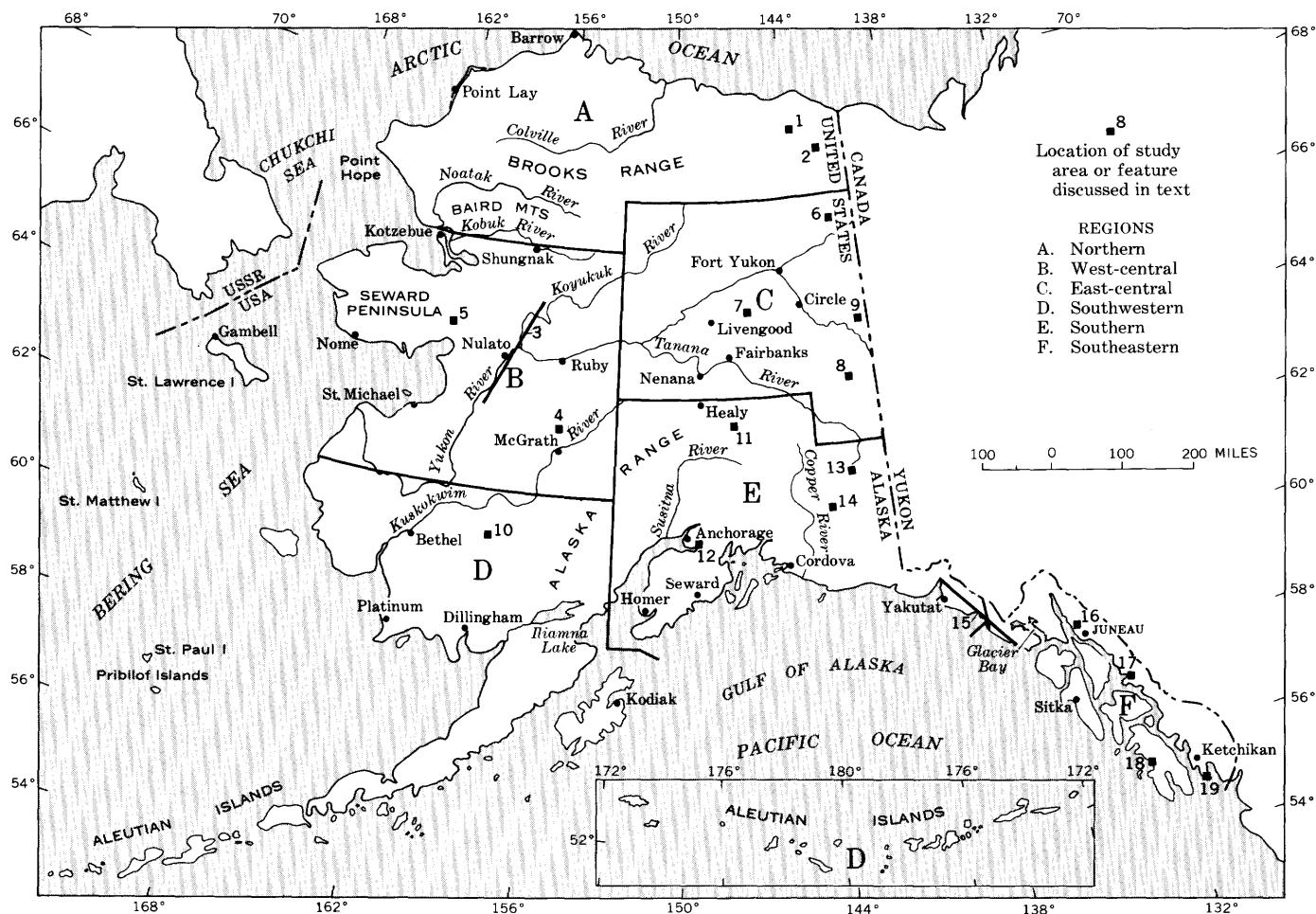
The adjacent and synchronous lithic assemblages of the mountainous core contain much less volcanic material and are inferred to be the distal seaward facies of the thick volcanic pile. The distal facies may have been underthrust beneath the thick part of the volcanic pile attached to the continental edge (a subduction zone), between the middle Eocene and the middle Miocene. Up arching during or following facies imbrication has produced the concentric pattern of today.

#### **Geochronology**

Plutonic rocks mapped by F. K. Miller in the Chewelah-Loon Lake area, Washington (loc. 13), have been dated by J. C. Engels using K-Ar methods. Three apparently distinct plutonic episodes are represented: the oldest about 200 m.y. (Late Triassic), the next about 100 m.y. (Late Cretaceous), and the youngest about 50 m.y. (Eocene).

### **ALASKA**

New scientific and economic findings of significance have resulted from many diverse field and topical in-



vestigations 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

##### **Paleozoic stratigraphy of the Mount Michaelson area, northeastern Brooks Range**

In 1969 a helicopter-supported field party with H. N. Reiser, W. P. Brosgé, J. T. Dutro, Jr., E. G. Sable, R. L. Detterman, and A. K. Armstrong returned to the Mount Michaelson area in the northeastern Brooks Range (locality 1, index map). Preliminary findings of special interest are reported in the following paragraphs.

The pre-Mississippian carbonate section was measured and sampled in detail by Brosgé and Dutro in the Shublik and Sadlerochit Mountains. The sequence is nearly 7,000 feet of Middle Devonian and older limestones and dolomites, and is now known to lie unconformably beneath Carboniferous sandstone and con-

glomerate in the cores of anticlinal structures. This carbonate sequence can be differentiated into the Nanook Limestone and Katakturuk Dolomite, and several distinctive lithologic subunits can be mapped in each formation. The stromatolitic and oolitic rocks, according to stratigraphic and petrographic analysis by Dutro, reflect deposition very nearly at sea level on a slowly subsiding shallow shelf. Where sufficient porosity and permeability are developed in the subsurface, this carbonate sequence might provide a target for petroleum exploration.

In addition to the carbonate sequence, Reiser mapped seven distinct lithologic units below the pre-Mississippian unconformity. Some of these units may be time equivalents, and more work will be needed to completely understand the stratigraphic relations. Of particular interest, moreover, is a series of mafic flows and pyroclastic rocks.

A study of the foraminiferal zonation and carbonate facies of the Lisburne Group (Mississippian and Pennsylvanian) in the central and eastern Brooks Range, was completed by Armstrong, Dutro (U.S. Geological

Survey), and B. L. Mamet (University of Montreal). The Lisburne Group carbonates contain foraminiferal assemblages assigned to zones of Osage (late Tournaisian), Early Mississippian, to Atoka (early Moscovian), Middle Pennsylvanian age. Representatives of both Eurasiatic and American cratonic microfaunas permit correlation with the original Carboniferous type sections in western Europe as well as with the standard Mississippian and Pennsylvanian sequences in the mid-continent region of North America.

Armstrong (r0666) also developed preliminary carbonate lithofacies maps and dolomite porosity-trend maps from the Mississippian-Pennsylvanian Lisburne Group on the North Slope of Alaska. Armstrong believes that porosity is extensively developed in the subsurface Lisburne Group and that conditions may locally be suitable for petroleum accumulation.

#### **Study of petroleum reservoir and source beds**

The Sadlerochit Formation, the main reservoir bed of the Prudhoe Bay oil field, is under intensive study by R. L. Detterman. The formation is from 600 to 1,200 feet thick in outcrops in the northeastern Brooks Range (loc. 1). Study of the sedimentary structures and the vertical facies successions within the Sadlerochit convince Detterman that it is mostly a nearshore deposit. Eleven detailed measured sections provide a lithofacies picture recording at least one major transgression in the Late Permian followed by regression in Early Triassic time.

The Shublik Formation (Triassic) is also under study and is of interest because of its phosphate content and because it may be the source rock of the petroleum in the Prudhoe Bay field. The Shublik is approximately 300 to 400 feet thick but is absent locally.

#### **Granitic intrusives of the eastern Brooks Range**

Geochemical investigations by W. P. Brosgé, H. N. Reiser, and E. G. Sable found tin associated with the granite plutons in the easternmost part of the Brooks Range (loc. 2). Near the United States-Canada boundary, tin concentrations are greater than average in the Mississippian or older Old Crow batholith, and 15 to 20 ppm Sn occur nearby in some of the stream sediments. Rhyolite associated with these granite bodies contains tin anomalies at Rabbit Mountain and Bear Mountain.

A previously studied granite in the same area, the Romanzof granite, contains about twice as much tin and beryllium as the average granite, but less than typical "tin granites". Tin concentrations of 10 to 300 ppm are common in the stream sediments. Tin is associated with anomalous amounts of lead and zinc in stream sediments along the northern and western margins of the granite and with anomalous amounts of lead and beryl-

lium near the sulfide zones previously mapped by Sable within the granite on the Okpilak River.

A satellitic(?) quartz monzonite body 8 miles south of the Romanzof pluton was mapped by Reiser and Sable. This is the first hornblende-bearing granitic rock found in the area, and studies by M. A. Lanphere have resulted in an age determination of  $430 \pm 15$  m.y. for this intrusive body.

#### **Shipborne magnetic data from the south Chukchi Sea**

During late summer of 1969, shipborne magnetic data were obtained by W. F. Hanna along track lines in the south Chukchi Sea. Reduction of the data to residual anomalies and preliminary interpretations indicate that the only area of strong positive anomalies (up to 350 gammas) is north-northwest of Cape Lisburne, within an area previously surveyed by the U.S. Coast and Geodetic Survey.

Estimated maximum depths to magnetic basement in areas of strong and weak anomalies average about 5.5 and 6.0 km, although a few depths are estimated locally as shallow as 1 to 4 km. The estimated maximum depths suggest that the magnetic source rocks may be part of the deep basement rather than a basement ridge, as previously proposed. A major aeromagnetic high on land north of Kivalina, reported by D. F. Barnes, was not detected 8 miles from the coast, suggesting a southwest seaward termination of the mafic intrusive-rock source.

#### **Thermal effects of a heated pipeline in permafrost**

An analysis by A. H. Lachenbruch (r0443) of a large heated pipeline buried in permafrost suggests effects that may adversely affect the environment and the integrity of the pipe. The mechanical effects result largely from loss of strength and (or) volume of much permafrost when it thaws. These changes could cause flow of the thawed material on extremely gentle slopes, or differential settlement leading to intense deformation of the pipe, if proper precautions are not devised. Lachenbruch found that the pipe will thaw permafrost in a relatively short time to depths of several tens of feet, even north of the Arctic Circle.

### **WEST-CENTRAL ALASKA**

#### **New structural interpretation in Yukon-Koyukuk province**

Recent mapping by W. W. Patton, Jr., along the margins of the Yukon-Koyukuk province (loc. 3) of west-central Alaska suggests that this Mesozoic structural province may have been a rift rather than a geosyncline as envisaged by earlier workers. It appears that Paleozoic and older(?) crystalline rocks which presently flank the province drifted apart in Triassic or Jurassic time and that the resulting rift was filled

with sedimentary and volcanic rocks in the Early Cretaceous. Low-potassium pillow basalts and associated mafic intrusives and serpentinites of probable Triassic and Jurassic age rim the province and may represent oceanic basaltic crust from the floor of the rift.

#### **Nixon Fork aeromagnetic survey**

Interpretation of an aeromagnetic survey from the Nixon Fork area (loc. 4) by L. A. Anderson, B. L. Reed, and G. R. Johnson shows that intrusives with which gold lode deposits are associated are characterized by negative magnetic anomalies, whereas barren intrusives, although of similar composition, are delineated by positive anomalies. This observation may be useful in locating additional gold-bearing intrusive bodies along the Iditarod-Nixon fault zone.

#### **Zoned pluton in eastern Seward Peninsula**

Recent mapping and petrologic studies in the eastern Seward Peninsula (loc. 5) by T. P. Miller show the Granite Mountain pluton to be a zoned intrusive body with a silica-undersaturated rim, a silica-saturated inner rim, and a core composed of silica-oversaturated rocks. Field relations suggest that the alkaline rimrocks were emplaced first, and that differentiation proceeded toward the core.

#### **Two cycles of thrust faulting on Seward Peninsula**

Geologic mapping at a scale of 1:250,000 by C. L. Sainsbury and T. L. Hudson demonstrated two cycles of thrusting on the Seward Peninsula. The earlier, beginning probably in Early Cretaceous time, involved easterly transport of thrust sheets, and produced imbricate thrusts and intense deformation in rocks of Paleozoic and Precambrian age. The younger, which involved northward thrusting, brought in the York Mountains allochthon and unmetamorphosed carbonates of latest Precambrian and early Paleozoic age. Both cycles of thrusting ceased prior to the emplacement in the York Mountains of granitic rocks with a radiometric age of  $71 \pm 10$  m.y.

### **EAST-CENTRAL ALASKA**

#### **Paleozoic-Mesozoic sequence in the southern Brooks Range**

Field studies in the southern Brooks Range (loc. 6) by W. P. Brosgé and H. N. Reiser indicate that Jurassic and Cretaceous rocks appear to rest directly on Permian rocks at several places near the Porcupine River. At Spike Mountain, a quartzite that contains ammonites, identified as Early Jurassic by N. J. Silberling, overlies a similar quartzite that contains Carboniferous or Permian brachiopods and corals identified by J. T. Dutro, Jr., and Mackenzie Gordon, Jr. To the south, on

the Salmontrout River, dark-gray paper shale rests with no obvious stratigraphic break on similar shale interbedded with limy-gray siltstone beds from which A. K. Armstrong has identified Pennsylvanian or Permian corals. A collection from the paper shale by B. P. Exploration Co. contains *Oxytoma* and an Early Jurassic *Amaltheus*, according to R. W. Imlay. Recently Dutro identified Permian brachiopods from gray siltstone on Howling Dog Creek, and D. L. Jones identified *Oxytoma?* of possible Jurassic age in a collection by B. P. Exploration Co. from overlying sandstone and shale. Flat-lying sandstone beds south of the Salmontrout River rest with probable angular unconformity on soft, dark shale. Species of *Astarte* and *Entolium* from the sandstone were identified as Jurassic or Cretaceous by Imlay; abundant foraminifers in the underlying shale are Permian, according to H. R. Bergquist.

#### **Geologic mapping in the Livengood quadrangle**

Two distinctive lithologic units, a massive limestone and a predominately basaltic volcanic rock unit, were mapped in the extreme northeastern part of the Livengood quadrangle (loc. 7) by R. M. Chapman, Michael Churkin, Jr., and F. R. Weber. Both units are well exposed in a tightly folded sequence in the vicinity of Mount Schwatka and on the ridges immediately to the north. The massive, medium- to dark-gray limestone apparently overlies the volcanic rocks, probably conformably. *Amphipora* from the limestone indicate a Silurian or Devonian age, and favositid corals, stromatoporoids, and crinoid columnals also suggest an early Paleozoic age.

The lithology, stratigraphic relationship, structural setting, and preliminary age determination of the Mount Schwatka area sequence are similar to the Tolovana Limestone and underlying basaltic volcanic rock sequence in the White Mountains 20 miles to the south, and these two sequences are probably correlative. Earlier mapping had shown the Mount Schwatka sequence as Devonian, and the White Mountains sequence as Silurian and Middle Ordovician.

#### **Geologic and geochemical survey in the Eagle quadrangle**

Geologic reconnaissance mapping of the Eagle quadrangle (loc. 8) by H. L. Foster and F. R. Weber delineated a belt of coarse-grained hornblende-bearing intrusive rocks trending northeasterly through the central part of the quadrangle. These igneous rocks intrude greenschist and amphibolite facies metamorphic rocks and crop out sporadically over a distance of about 65 miles. The belt is up to 20 miles wide but is much narrower in most places. The rocks range in composition from hornblende gabbro to hornblende

granodiorite. They are postulated to be of Mesozoic age and may lie along the trend of an ancient fault.

Geochemical data gathered by Foster, Weber, and S. H. B. Clark show that many of the streams in the Fortymile River and Seventymile River drainage areas and near Mount Harper have slightly anomalous amounts of one or more metals in the stream sediments. Some of the samples with anomalous amounts of metals are from streams not previously mined and probably not prospected for metals other than gold. Although the geochemical anomalies are not large or extensive, they indicate many places meriting additional checking and sampling. Geochemical sampling near the margins of several previously unmapped igneous intrusions along the Middle Fork of the Fortymile River suggest several other areas which may be worthy of further mineral exploration.

#### **Stratigraphy and age of the Tahkandit Formation**

Recent studies by R. E. Grant and E. E. Brabb yield significant new data on the stratigraphy and age of the Tahkandit Limestone (loc. 9). The Tahkandit Limestone consists of two units, a lower glauconitic sandstone and conglomerate unit and an upper, thicker, unit of bioclastic white limestone. The total thickness is about 350 feet rather than the 500 to more than 1,000 feet of previous reports. The formation is much thicker in nearby Yukon Territory, Canada, where it is also divisible into a lower clastic and an upper carbonate unit. Although lithologies of the Alaskan and Canadian sections are dissimilar in detail, correlation by means of brachiopods suggests that they are of similar age. The lower unit of the Tahkandit in the Yukon was correlated with the Assistance Formation (of the Canadian Archipelago) of Leonard age on the basis of brachiopods, fusulinids, and cephalopods. Brachiopods in the upper unit of the Tahkandit indicate a Guadalupe age, most nearly correlative with the fauna of central East Greenland and unnamed units above the Assistance Formation.

### **SOUTHWESTERN ALASKA**

#### **Geochemical investigations of mercury distribution**

Geochemical investigations by A. L. Clark, J. M. Hoare, and W. H. Condon provided significant data on the distribution of mercury in an 800-sq-mi area in the Taylor Mountains quadrangle (loc. 10). Preliminary results indicate a regional threshold value of 0.35 ppm and a local threshold value of 0.80 ppm Hg in non-mineralized rock. Stream sediments from the same area show a regional threshold of 0.20 ppm Hg and a local threshold of 0.65 ppm Hg. Values above 1 ppm Hg

in stream sediments are considered strongly anomalous.

Studies near the Cinnabar Creek mine show that the strongest metallic halos around the mine are defined by mercury, arsenic, and antimony. Sediment samples from streams draining the mine show anomalous mercury values persisting up to 6 miles away from the mine area. The study also suggests that mercury present in stream-sediment samples is not particulate. Wide dispersion of mercury away from known deposits and the probable nonparticulate nature of its distribution indicate that normal stream-sediment sampling is an effective means of exploring for mercury deposits in southwestern Alaska.

### **SOUTHERN ALASKA**

#### **Lode gold occurrences in the western Clearwater Mountains**

Two centers of gold mineralization in the Clearwater Mountains were identified by T. E. Smith during recent work in the Healy A-1 quadrangle (loc. 11). The centers at both Timberline Creek and Black Creek are located along an east-west-trending shear zone near its intersections with complimentary faults trending N. 45° E. to N. 60° E.

These sites of structural weakness apparently guided emplacement of small diorite and quartz diorite stocks. Recurrent movement along the faults fractured and locally sheared the intrusives, providing discontinuous dilatant areas for subsequent gold-quartz-carbonate vein deposition. Although most of the auriferous veins are localized within the fractured intrusives, nearly all limonitic shear zones in both intrusive and country rock also contain anomalous concentrations of gold in the range 0.02 to 20 ppm. The coincidence of gold centers with intrusives appears to be a tectonic association only.

#### **Inverted metamorphic zonation in the northern Clearwater Mountains**

Recent mapping in the Healy A-1 and B-1 quadrangles (loc. 11) by T. E. Smith established that pelitic rocks underlying the Valdez Creek area form a metamorphic sequence of the Barrovian series, increasing in grade upsection and northward. The progression of both thermal and dynamic components of metamorphism has produced rock types varying from chloritic argillites and graywackes with preserved sedimentary structures in the south through biotite-garnet schists to kyanite-bearing layered gneisses in the north.

A concordant sill-like body of foliated quartz diorite extends east-west for over 7 miles across the gneissic part of the section. Earlier workers considered the southern margin of this body to be the contact of a

large batholith and attributed the metamorphic gradation to contact effects. The foliated sill may represent either a zone of intense dislocation and near-anatectic recrystallization or, alternatively, a strongly metamorphosed intrusive body emplaced concordantly prior to the last dynamothermal episode.

#### **Changes in southern Alaska gravity field**

Continued analysis of the southern Alaska gravity field and its changes during the 1964 earthquake convinced D. F. Barnes that the measured changes were real and resulted from mass changes within the crust or mantle. Simultaneous changes in ground-water level probably influenced the measurements at Anchorage and may have made other scientists critical of the interpretation. The largest gravity change was measured at Middleton Island where the geologic record documents many late Cenozoic crustal uplifts similar to the one that occurred during the earthquake. If the measured gravity changes are extrapolated backward with the aid of this geologic record, there seems to have been sufficient deformation to explain the present large gravity anomaly and to suggest that processes of isostatic adjustment have accompanied the crustal deformation. Comparison of this southern continental-margin gravity anomaly with one of similar magnitude on the north coast suggests that the latter may have had a very different and nontectonic origin.

#### **Mapping of western Chugach Mountains**

Features generally thought to indicate rapid deposition of unsorted sediment were recognized by S. H. B. Clark in parts of an alternating metagraywacke and slaty argillite sequence in the western Chugach Mountains north of Turnagain Arm (loc. 12). These rocks, of Jurassic and (or) Cretaceous age, are deformed into a series of tight folds with cleavage or schistosity nearly parallel to axial planes or converging upward. In the Anchorage area, metamorphosed clastic rocks (including graywacke and argillite) and associated greenstones and minor amounts of metachert and marble crop out on the west flank of the mountains and appear to overlie the Jurassic and (or) Cretaceous sequence. Zeolites and minerals indicative of prehnite-pumpellyite facies metamorphism have been identified in the clastic rocks and associated greenstones. Bedding is obscured in this unit and folds are rarely seen, but the orientation pattern of cleavage or schistosity is similar to that in the metagraywacke and slaty argillite sequence of the western Chugach Mountains.

#### **Glacial event dated in Anchorage area**

Ernest Dobrovolsky and H. R. Schmoll reported that radiocarbon age determinations by Meyer Rubin on

marine shells from the Anchorage area have dated the Bootlegger Cove Clay as about 14,000 years old. The overlying Elmendorf moraine, previously considered Wisconsin maximum, is thus very late Wisconsin in age, and the underlying drift of the Knik Glaciation in its type area probably represents the main Wisconsin Glaciation. Thus the Woronzofian transgression represented by the Bootlegger Cove Clay reflects the initial rise of sea level after maximum lowering during the Wisconsin Glaciation.

#### **Major fault system in eastern Alaska Range**

Detailed reconnaissance mapping in the eastern Alaska Range (loc. 13) by D. H. Richter and N. A. Matson, Jr., revealed the presence of a major fault system that may be a link between the Denali lineament in south-central Alaska and the Chugach-Fairweather structure along the Gulf of Alaska. This major fault system, referred to as the Totschunda fault, splits off the Denali lineament at an angle of about 15° near Mentasta Pass and can be traced southeasterly more than 100 miles before it is lost in the high ice-covered eastern Wrangell Mountains. Offset drainages and glacial deposits on a segment of the Totschunda system indicate as much as 6 miles of right-lateral displacement, probably since late Pliocene time. Vertical movement along the fault system has also been considerable with the southern block upthrown as much as 5,000 feet.

#### **Cretaceous age of major rock unit in Chisana area**

Field investigations and paleontological studies in the eastern Alaska Range (loc. 13) by D. H. Richter and D. L. Jones unequivocally show that a thick section of volcanic and volcanoclastic rocks in the Chisana area are Cretaceous in age and not Devonian as designated by early workers.

These studies clarify what was once a vexing stratigraphic and structural problem; the oldest rocks now known to be exposed south of the Denali fault in the eastern Alaska Range are Permian in age. The new Cretaceous unit, which apparently has limited areal extent but which may be as much as 10,000 feet thick, consists principally of andesitic volcanic breccias and conglomerates and subordinate andesite flows, volcanic graywacke, and argillite. The finer grained volcanoclastic rocks occur chiefly in the lower 1,000 feet of section and contain abundant *Inoceramus* prisms.

#### **Possible revision of the Strelina Formation in the McCarthy quadrangle**

During the course of field studies in the McCarthy C-8 quadrangle (loc. 14), E. M. MacKevett, Jr., and G. R. Winkler noted strong similarity between rocks



mapped by earlier workers as Strelna Formation (Mississippian) and parts of the Skolai Group (Permian? and Permian) in the McCarthy B-4 and C-4 quadrangles. Identifiable invertebrates in two fossil collections from the C-8 quadrangle were studied by R. E. Grant and found to be Permian in age and similar to fossils collected from the Hasen Creek Formation (Lower Permian) of the Skolai Group. No Mississippian faunal elements were found. Because the collections were from rocks within or near the loosely defined type locality of the Strelna, some revisions are in order and are contemplated after more detailed field-work and additional paleontologic studies.

#### **Nature and extent of the Fairweather fault**

The Fairweather fault (loc. 15), a major active strike-slip fault in southern Alaska, was mapped from Lituya Bay northwestward to the Hubbard Glacier near the head of Yakutat Bay. Fresh scarps and tension cracks at several localities along the fault trace probably represent surface ruptures that occurred during the "Lituya" earthquake of July 10, 1958. If so, these features indicate that surface dislocations associated with the earthquake extended 155 miles northwest of the instrumental epicenter, and that right-lateral offset near the northwestern end of the fault was at least 4 feet. Geologic mapping in the Yakutat and Mount Saint Elias quadrangles demonstrates that the northwest-trending Fairweather fault terminates by merging at an oblique angle into the east-west-trending Chugach-Saint Elias system of thrust faults near the head of Yakutat Bay. The Fairweather fault does not extend northwestward across the Saint Elias Mountains into interior Alaska as has been postulated by a number of geologists and geophysicists who have speculated on its significance with respect to the major tectonic elements of Alaska.

### **SOUTHEASTERN ALASKA**

#### **Metamorphic isograds in the Juneau area**

The metamorphic isograd pattern along nearly 40 miles of the schist belt adjoining the western margin of the Coast Range plutonic complex between Taku Inlet and the Eagle River valley (loc. 16) was delineated by geologic mapping by D. A. Brew and A. B. Ford. Results verify the presence of Barrovian-type metamorphic zonation as mapped by Forbes<sup>42</sup> in a traverse across the belt near Juneau. Metamorphic grade increases progressively northeastward across regional structural trends from chlorite zone near Juneau to sillimanite zone along the western gneissic border of

the complex near Cairn Peak. The isograds mapped by Forbes are now known to extend for many miles to the northwest and to the southeast, and their three-dimensional geometry can be inferred owing to high local relief of the region. Isograd surfaces generally trend northwestward and dip moderately to steeply northeastward, more or less paralleling foliation and compositional layering in the schists. A marked discordance in plan exists between the regional isograd pattern in the schist belt and the western margin of the plutonic complex. The discordance is displayed by the systematic northwestward truncation of isograds marked by the first appearance of sillimanite, of kyanite, of staurolite, and of garnet. The biotite isograd probably extends northwestward beyond Eagle River valley but apparently is cut by the complex south of Berners Bay. Hypotheses of evolution of gneisses and granitic rocks in this part of the Coast Range plutonic complex and of the history of the adjoining schist belt must take into account this regionally transgressive relationship.

#### **Coast Range batholith and associated metamorphic rocks in the Port Houghton area**

Lithic units of probable Mesozoic age mapped in the Port Houghton area (loc. 17) by A. L. Clark and others differ from other Mesozoic rocks along the border of the Coast Range batholith in their relatively high proportion of clastic to volcanic rocks. Metamorphic zonation is generally similar to other areas, except for an unusually abrupt and complicated transition from greenschist facies to amphibolite facies and for an unusually broad kyanite zone within the amphibolite facies rocks immediately adjacent to the batholithic complex.

The conspicuous metamorphic foliation which dips to the east-northeast has been affected by a later folding in which northwest-trending nearly vertical axial planes predominate. This complicated structural history is similar to that in the nearby Pybus-Gambier area of Admiralty Island and may be in the same large structural province.

The batholithic complex of probable Cretaceous and (or) Tertiary age is composed of granitic and gneissic phases and locally appears to have a multiple intrusive history; however, it is compositionally very homogeneous. The average composition is that of a quartz diorite. Locally the various intrusive phases are separated by a one-half mile to 1-mile zone of migmatite.

#### **Reconnaissance mapping of western Prince of Wales Island and nearby islands**

Reconnaissance geologic and geochemical investigations were conducted by A. L. Clark and others on

<sup>42</sup> Forbes, R. B., 1959, The geology and petrology of the Juneau ice field area, southeastern Alaska: Univ. Washington, unpub. Ph. D. thesis, 265 p.

west-central Prince of Wales Island (loc. 18) and on several of the smaller islands to the west of Prince of Wales Island.

Reconnaissance mapping of the west-central part of Prince of Wales Island shows that the layered rocks in the area are principally graywacke, argillite, basalt, conglomerate, and minor limestone of the Descon and Port Refugio Formations. The layered rocks are cut by plutonic rocks of Paleozoic and younger age which range from quartz monzonite to gabbro in composition. All the rocks are cut by intermediate to mafic dikes and sills. In the Pin Peak area much previously mapped intrusive rock was found to be contact-metamorphosed volcanic rock, probably part of the Descon Formation. Several major faults were recognized, and in the Trocadero Bay area a fault zone is marked by numerous cold-water springs which are depositing  $\text{CaCO}_3$ , limonite, and very minor amounts of gold ( $<0.04$  ppm). The cold-water springs can be traced for more than 6 miles.

Strata of Ordovician age, previously recognized only in a 30-mile-long belt on western Prince of Wales Island, were found to be much more widely distributed in this region as a result of fossil collections made by A. T. Ovenshine and Michael Churkin, Jr. Collections of Middle Ordovician graptolites from graywacke interbedded with pillow lava have been found as far north as Port Protection on the northern tip of Prince of Wales Island, as far east as Thorne Island near Clarence Strait, and as far south as Breezy Bay on Dall Island. Strata of Ordovician age are the oldest known rocks in southeastern Alaska.

Greenschist to amphibolite facies metamorphic rocks make up the southern one-fourth of Dall Island and the southern tip of Sukkwan Island. These rocks are of much higher metamorphic grade than other rocks of the area and had not previously been described. A marked difference in structural trend between the northern and southern portion of Dall Island was also noted. Foliation in metamorphic rocks on the south has a dominantly north-northeast trend, whereas the foliation in the north has a dominantly west-northwest to east-west trend. West-northwest to east-west structural trends are marked by large isoclinal folds and possible thrust faults. Possible large-scale thrusting was recognized for the first time in the area.

#### **Lower Paleozoic pluton on Annette Island**

As a result of continued mapping of Annette Island (loc. 19) by H. C. Berg, it is now recognized that Annette Island consists of two geologically distinct terranes—mainland Annette Island and Metlakatla Peninsula, a large southwestern appendage of the island. The terranes contrast markedly in physiography, in origi-

nal rock types, and in style and grade of metamorphism. Mainland Annette is mountainous and consists of a core of Silurian trondhjemite (the Annette pluton) and a fringe of predominantly greenschist facies regionally metamorphosed calcalkaline bedded rocks that range in age from Silurian (or older) to Jurassic. In addition to the Annette pluton, which has yielded a K-Ar age of 416 m.y., there are two other plutons. One is Cretaceous quartz diorite with a K-Ar age of 87 m.y.; the other is diorite inferred to be Jurassic or Cretaceous. Metlakatla Peninsula is a lowland underlain mainly by greenschist-to-amphibolite facies metamorphosed kerotophytic and calcalkaline bedded rocks intruded by two foliated quartz diorite plutons—one Silurian (?) and one middle or upper Paleozoic (?). The metamorphosed bedded and plutonic rocks are in contact with an ultramafic body thought to have been emplaced tectonically in Cretaceous time. The Peninsula is also distinguished by conspicuous thrust faults, which, along with other evidence, lead to the interpretation that the terranes are separated by a major eastward-dipping thrust zone having an apparent relative displacement of at least 5 miles.

### **PUERTO RICO**

At the close of 1969, about 2,500 sq mi of the approximately 3,435-sq-mi area of Puerto Rico and adjacent islands had been covered by geologic mapping at the scale of 1:20,000. This progress is a result of a continuing long-term project of the U.S. Geological Survey in cooperation with the Industrial Research Department of the Puerto Rico Economic Development Administration. In addition during 1969, new projects undertaken by the Geological Survey in cooperation with the Puerto Rico Department of Public Works included the detailed study of metallic mineral deposits, extensive geochemical sampling, and the establishment of a geochemical laboratory in Puerto Rico.

#### **Metallogenic map**

Compilation of a preliminary metallogenic map of Puerto Rico was completed by D. P. Cox and R. P. Briggs. The map shows tectonic and igneous features, areas of hydrothermally altered rock, as well as locations of mines and mineral occurrences. The mines and mineral occurrences are classified in a symbol system that closely follows the one developed for the metallogenic map of North America. The system indicates the content and form of each deposit, the character of associated igneous rocks and hydrothermal alteration, and the type and age of enclosing rock. The map illustrates several important facts about the distribution of mineral deposits which have been recognized previ-



ously by geologists working in Puerto Rico but not described in the literature. Occurrences of metallic minerals are not randomly distributed over the island but are grouped around plutons and in belts parallel to the regional structure. Porphyry copper and molybdenum deposits, chalcopyrite-quartz and minor gold-quartz veins, and zinc-lead-silver deposits are grouped around the Utuado batholith (locality 1, index map) and the Ciales stock (loc. 2) in the central part of the island. Skarn deposits containing chalcopyrite associated with either magnetite or pyrrhotite are adjacent to the San Lorenzo batholith (loc. 3) and Rio Blanco stock (loc. 4) near the east end of the island. Manganese veins in volcanic rocks and limestone follow the belt of lower Tertiary rocks trending northwest from Juana Díaz to Aguada (between loc. 5 and loc. 6). Barite veins and possibly important gold-silver deposits are found in the serpentinite-chert complex which forms the southwest corner of the island (loc. 7). Metallic mineral occurrences do not seem to be closely associated with the large belts and irregular areas of hydrothermally altered volcanic rocks of eastern Puerto Rico.

#### Mineral resources

In an outline of the mineral resources of Puerto Rico, R. P. Briggs (r0708) pointed out that deposits of non-metallic minerals, metallic minerals, and mineral fuels are known to be present. Nonmetals valued at more than \$40 million are extracted annually. They are chiefly limestone, sand, gravel, and stone, but some clay, silica sand, and hydrothermal minerals are also mined, and moderate quantities of salt are produced by evaporation of sea water. Deposits of very pure dolomite are also present. In early 1970, no metals were being mined, but mining of three known porphyry copper deposits is expected to begin in the near future. These deposits contain more than 200 million tons of ore with a copper grade of less than 1 percent and minor quantities of precious metals. Other metalliferous deposits of lesser promise are laterites. One such deposit consists of more than 40 million tons of potential ore containing 0.8 percent Ni and 0.08 percent Co. Metals present in Puerto Rico also include iron (in laterites, replacement bodies, and beach sands), gold, silver, manganese, molybdenum, lead, and zinc.

Extensive deposits of peat occur in coastal areas, and thin uneconomic lignite seams are also present. The structure and lithologic character of the postvolcanic Oligocene and Miocene strata suggest possibilities for oil and gas. The four deep test wells in these strata were dry, but four wells do not constitute an adequate test of the area. No promising deposits of radioactive fuels have been found.

#### Magnitude of faulting

In the course of detailed mapping in the Maricao quadrangle, western Puerto Rico (loc. 8), D. H. McIntyre found new evidence bearing on the character and magnitude of movement on the west-trending Cordillera fault. Left-lateral displacement of about 10 km is suggested by apparent offsets of a small pluton, of another older wrench fault, and of a key stratigraphic contact. The sense and magnitude of movement deduced along the Cordillera fault are of the same direction and order as those suggested for other large pre-middle Tertiary faults in Puerto Rico. By contrast, W. H. Monroe found that post-middle Tertiary faults in southern Puerto Rico (loc. 9) are chiefly dip-slip in character. He reports that middle Tertiary rocks in southern Puerto Rico are complexly faulted, and that faults follow most south-trending valleys or cross the area in a generally westerly direction. Some of the faults have displacements of several hundred meters and could form traps for petroleum.

#### Eocene Foraminifera in oil test well

Preliminary study of larger Foraminifera in cuttings from three oil and gas test wells drilled on the south coast of Puerto Rico was completed by K. N. Sachs, Jr. In one of the wells, Commonwealth of Puerto Rico No. 1, about 1.5 km east of the village of Pastillo, Santa Isabel quadrangle (loc. 10), middle Eocene species of *Discocyclina* and *Asterocyclina* were found at a depth of 3,670 feet (1,119 m), and appear to lie immediately below the Juana Díaz Formation (Oligocene). In an earlier study of this material, the oldest Tertiary sedimentary rocks in any of these wells were considered to be Oligocene.

#### Late Early Cretaceous depositional environment

Volcanic strata initially identified informally by a number of workers in east-central Puerto Rico as Formation D, Formation K, and pre-Robles rocks were grouped by R. P. Briggs<sup>43</sup> and labeled formally as the Torrecilla Breccia of Early Cretaceous, probably Albian Age. The Torrecilla ranges in thickness from 0 to more than 2,000 m and is composed largely of very

<sup>43</sup> Briggs, R. P., 1969, Changes in stratigraphic nomenclature in the Cretaceous System, east-central Puerto Rico: U.S. Geol. Survey Bull. 1274-O, p. 07-015.

thick bedded tuff breccia, tuff, lava, and lava breccia. In the eastern outcrop area (loc. 11) of the Torrecilla, a limestone member crops out sporadically in the base, there are a number of lenses of reef limestone, red beds are found near the top, and a limestone member of the Robles Formation rests on the Torrecilla with apparent unconformity. To the west (loc. 12), the base of the Torrecilla is not exposed. Here no limestone lenses are found in the unit, a thick tuff member occurs at the top and grades upward into the Robles Formation, and the limestone member is absent from the base of the Robles.

These lateral lithologic variations indicate that shallow-water marine and subaerial, maritime, conditions occurred during Torrecilla and early Robles time in the eastern area, whereas less than 20 km to the west, the Torrecilla Breccia and lower Robles Formation apparently were deposited wholly at water depths where no reef organisms could flourish. This indicates that there was a westerly slope to the upper Lower Cretaceous volcanic pile in the crustal block that now is east-central Puerto Rico. In contrast, volcanoclastic materials of Upper Cretaceous and lower Tertiary volcanic piles were deposited on generally northerly-to-northeasterly and southerly-to-southwesterly slopes. It is possible therefore that the upper Lower Cretaceous volcanic pile had an elongation considerably at variance to that of later volcanic piles in Puerto Rico, which generally were elongate in northwesterly and westerly directions.

#### **Bibliography of geology**

The bibliography of Puerto Rican geology for the period 1866–1968 prepared by Marjorie Hooker (r0083) brings together citations to more than 500 articles concerning the geology and mineral resources of the island, nearby small islands, and nearby submarine areas including the Puerto Rico Trench. The index, both topical and geographic, is based on actual inspection of the works indexed. With the growing interest in economic mineral resources in Puerto Rico and the role of the Caribbean area in island-arc genesis, sea-floor spreading, and continental drift, the bibliography will prove to be a tool of continuing usefulness.

#### **Chemical analyses of Antillean rocks**

As a result of work done chiefly by Marjorie Hooker, about 90 percent of the published chemical analyses of igneous and metamorphic rocks occurring on islands of the Greater Antilles and Lesser Antilles are now on magnetic tape in a form retrievable by rock type, location, and other parameters.

#### **Underthrusting in the Lesser Antilles**

Recent seismicity studies<sup>44</sup> demonstrated that Atlantic oceanic crust most likely is being thrust beneath the Lesser Antilles volcanic island arc at the eastern margin of the Caribbean Sea. The volcanicity and other features of the area support this theory. Adopting the premise that from a given point on the mid-Atlantic ridge approximately equal volumes (thus lengths) of "new" oceanic crust have been spread east and west, with a slight bias toward westward spreading (for example, 3,400 km W. versus 3,200 km E. measured from one point of the North Atlantic ridge, and 2,400 km W. versus 2,200 km E. measured from one point on the northern South Atlantic ridge), R. P. Briggs concluded that the linear extent of oceanic crust thrust beneath the Lesser Antilles may be about 1,300 km. That is, the distance from a point on the Lesser Antilles arc to the mid-Atlantic ridge opposite the Lesser Antilles is about 1,800 km, whereas the distance from the same point on the ridge to a conjugate point in Africa is about 3,000 km. If this premise is accepted, and if underthrusting commenced penecontemporaneously with the opening of the Atlantic, perhaps 160 m.y. ago, then the Atlantic oceanic crust has been thrust under the Lesser Antilles at an average rate of about 0.8 cm/yr.

#### **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, and 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.

<sup>44</sup> Molnar, Peter, and Sykes, L. R., 1969, Tectonics of the Caribbean and Middle America regions from focal mechanisms and seismicity: *Geol. Soc. America Bull.*, v. 80, p. 1639–1684.

Sykes, L. R., 1966, Seismicity and deep structure of island arcs: *Jour. Geophys. Research*, v. 71, no. 12, p. 2901–3006.

Sykes, L. R., and Ewing, M., 1965, The seismicity of the Caribbean region: *Jour. Geophys. Research*, v. 70, no. 10, p. 5065–5074.

### LARGE-SCALE GEOLOGIC MAPS

Large-scale geologic mapping, principally at scales of 1:24,000 and 1:62,500, constitutes about four-fifths of the geologic-mapping program of the 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 ultimate goal is to obtain complete detailed geologic map coverage of the entire Nation.

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

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 of 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 alignments, subway routes, and so forth. 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 about one-third 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, Nevada, Colorado, and Nebraska within a few years. Single-sheet 1° by 2° geologic maps have been started in parts of Washington, Oregon, Idaho, Montana, Wyoming, Utah, Arizona, New Mexico, Iowa, North Carolina, South Carolina, Tennessee, and Virginia.

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 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 viewing 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. Only Texas and the southern Appalachians are not yet completed. This new compilation will supersede the existing map published almost 40 years ago and will show the vast increases in knowledge gained during the last few 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 International Union of Geo-

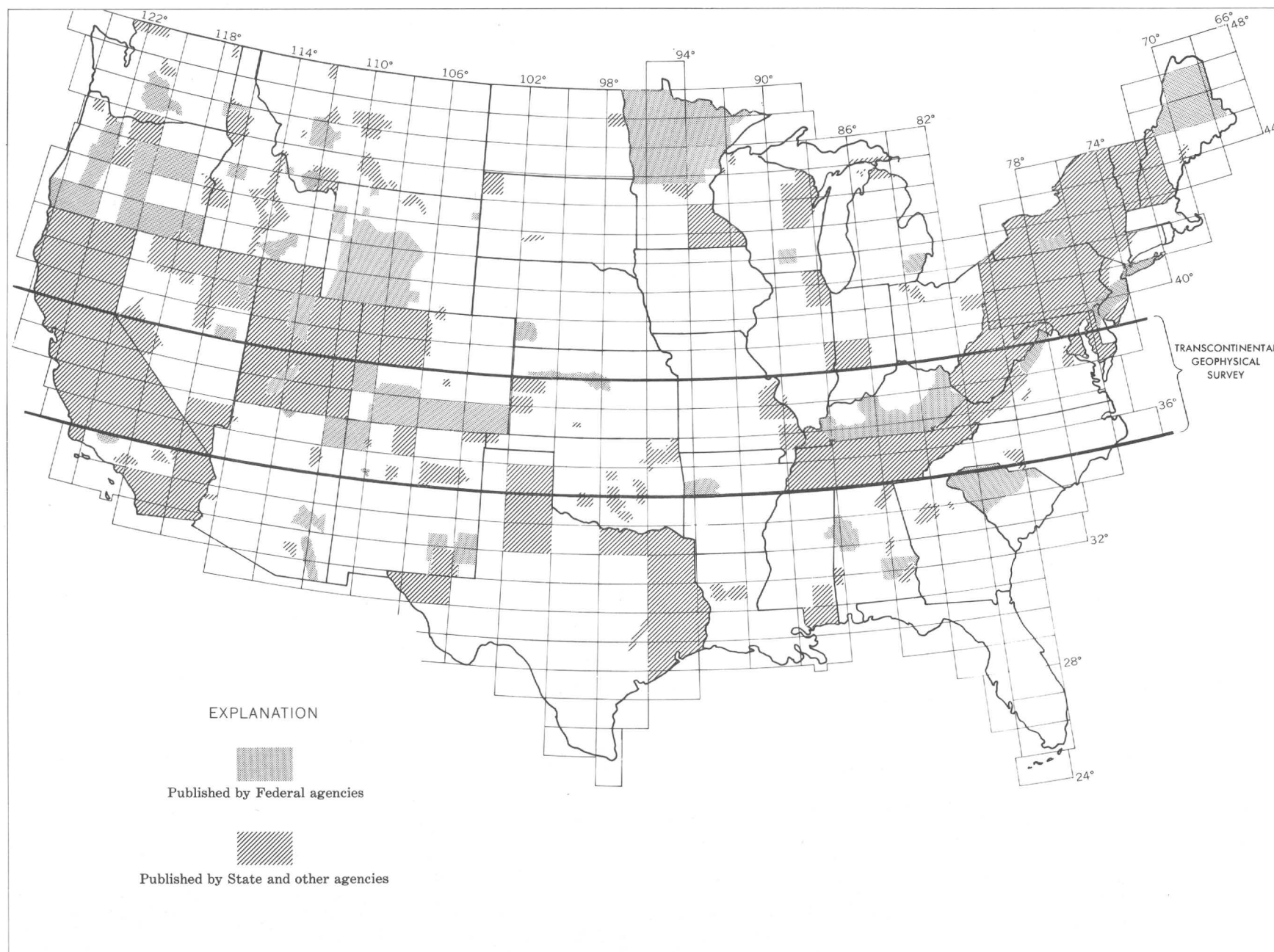


FIGURE 2.—Index map of the conterminous United States, showing 1:250,000-scale geologic maps published as of June 30, 1970



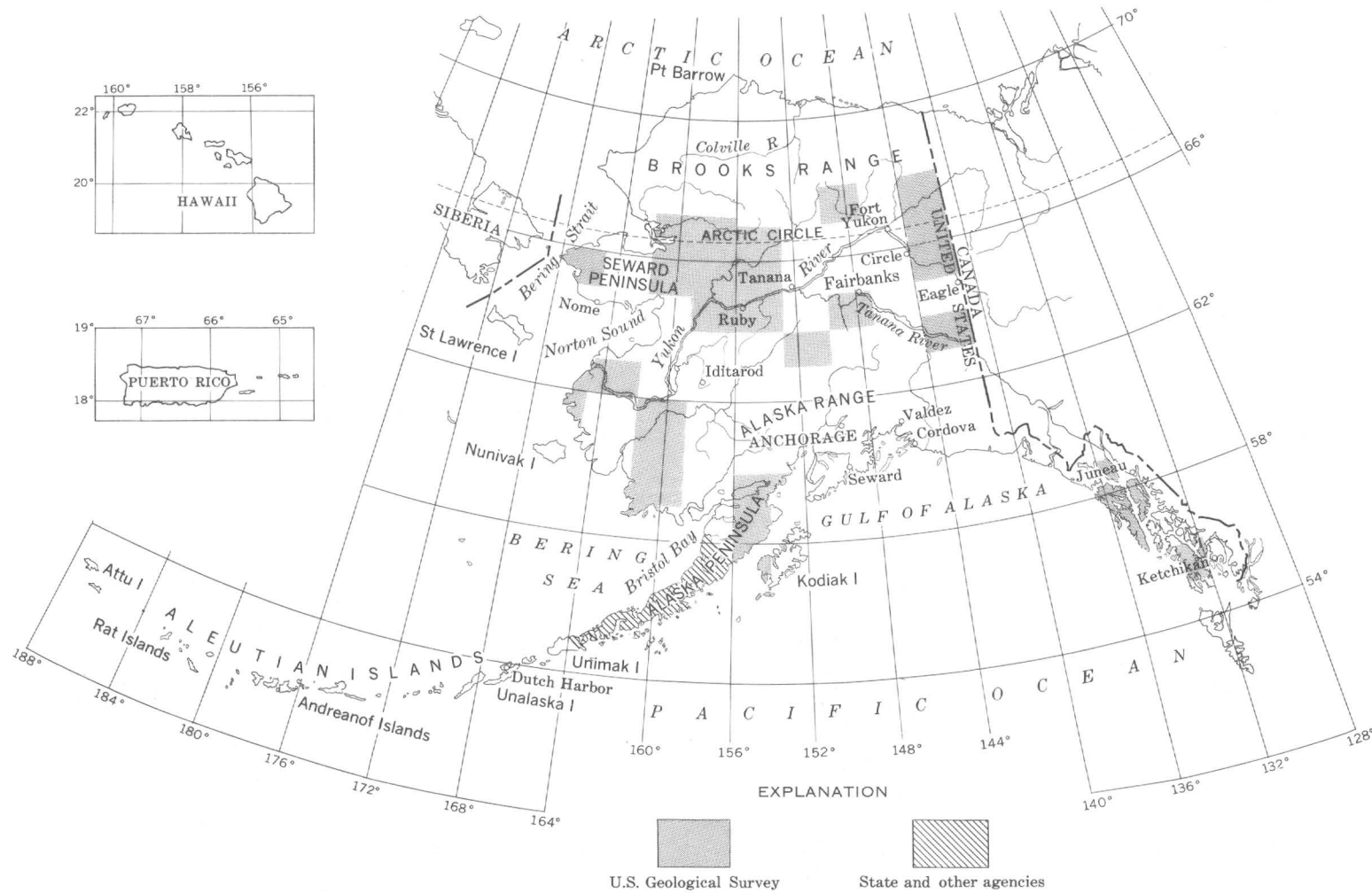


FIGURE 3.—Index map of Alaska, Hawaii, and Puerto Rico, showing 1:250,000-scale geologic maps published or open filed as of June 30, 1970.



logical Sciences. 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 North America, scale 1:5,000,000.

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. Compilation is by a committee convened by H. L. James, in cooperation with national geological surveys of North America. The map will show isograds based on minerals in pelitic schists, regional metamorphic facies, and metamorphic facies series.

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

This is the first unit in a planned map of North America. It shows biotite, garnet, staurolite, kyanite, andalusite, and sillimanite in pelitic schists, areas of greenschist and amphibole mineral facies, and facies series characterized by andalusite-sillimanite and by kyanite-sillimanite transitions.

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 surveys, investigations and research on occurrence, quality, quantity, distribution, utilization, and movement of surface

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

Surface-water studies during fiscal year 1970 included collection and analysis of data on streamflow, floods, and quality of water. Data on streamflow were collected at about 10,000 stream-gaging stations, nearly 6,600 of which are equipped with digital recorders, and at some 1,300 lake- and reservoir-level stations. Some 800 quadrangle maps showing flood-prone areas were published in 1970, along with 120 pamphlets of flood-prone areas. Continued expansion occurred in studies of quality of surface water—currently, at approximately 4,100 water-quality stations in the United States and its possessions. Parameters measured include selected major cations and anions, specific conductance or dissolved solids, pH, and other selected quality characteristics. Other parameters, measured as needed, include trace elements, phosphorous and nitrogen compounds, detergents, pesticides, radioactivity, phenols, biochemical oxygen demand, and coliform bacteria. Streamflow records are collected at most of the water-quality stations, and water temperature is either recorded continuously or at the time of sampling at about 3,165 water-quality stations. Sediment data are obtained at about 770 locations.

Daily measurements of ground-water levels were made in about 2,500 wells, and periodic measurements in about 25,500 wells. About 900 areal water-resources studies and some 600 research projects are now in progress. The total area in the United States covered by studies related to ground-water resources amounts to about 2 million sq mi or nearly two-thirds of the country.

About half a million sq mi was studied in 1968, including over 215,000 sq mi covered by comprehensive river basin planning studies. Of water-resources studies currently being carried out, about 145 studies are directly related to urban-hydrology problems and about 170 indirectly related thereto. In addition to the studies of fresh water, studies of saline ground water and brackish water in estuaries are being carried out.

When the International Hydrological Decade (IHD) program was established in 1965, certain elements of the national water-data network operated by

the U.S. Geological Survey in cooperation with State and other Federal agencies, were chosen as contributions to the IHD program to show the status of the Nation's water resources. Three mid-decade meetings, (1) International Conference on the Practical and Scientific Results of the International Hydrological Decade, (2) International Cooperation in Hydrology, and (3) Fifth session of the coordinating council of the IHD, were held in Paris in December 1969. E. L. Hendricks served as Chairman of the United States delegation at the conferences, and R. L. Nace served as a member of the delegation.

The Geological Survey as part of the IHD program is maintaining a network of river stations for observing stream discharge, chemical quality, and suspended sediment. This network is providing a general index of the discharge of water and of dissolved and suspended material from the continent to the oceans. Observations at 23 lake stations and a number of selected wells also are included in the program; these furnish data on the chemical quality of lakes, reservoirs, and ground water, and on water levels.

The 57 hydrologic bench-mark stations of the national network are included in the IHD program. These provide information on natural hydrologic conditions removed from the effects of man's activities. Radiochemical analyses, in which alpha, beta, radium, and uranium determinations are made, are performed at 46 of the bench-mark stations annually. Annual analyses of pesticides in the water and bed material are also made at these stations. Fifty-two of the water-quality measurement stations are maintained as part of the IHD program. Daily measurements are made at 10 stations, and monthly or periodic measurements at the remainder.

In addition, 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.

A resume of certain of the activities in the IHD program concludes the water resources section of this chapter (p. A94-A95), and more detailed reports on some of them appear in other sections, where appropriate.

The use of computers for studying hydrologic systems and for storing data continued to increase in fiscal year 1970. Records of about 200,000 station years of streamflow data and information on some 30,000 ground-water wells and 4,000 water-quality stations are available on a set of 40 magnetic tapes.

Studies of land subsidence, including studies in many areas only recently affected by subsidence, and

of ground-water recharge for countering both subsidence and depleted ground-water resources, continued on an expanded scale.

The principal publications for basic hydrologic data are in the following series of U.S. 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 for the entire country, by drainage-basin areas, and notable floods each year.

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

## ATLANTIC COAST REGION

Water problems in the Atlantic coast region are similar to those in the other three water-resources regions of the United States in that the distribution of water of suitable quantity and quality is variable in time and space and in that the problems themselves are widely disparate, ranging from lake eutrophication to sea-water intrusion of aquifers. However, the problems in the Atlantic coast region differ from those in the other regions, perhaps mainly in degree and impact, because both people and water are more abundant here, in general, than elsewhere in the Nation. But, the blessing of an abundance of water can become a hardship during a flood—especially where more people can be affected and where more property can be damaged. And, abundant water can be a medium of disaster in a heavily populated region—if the water is polluted beyond the capacity of available treatment facilities to treat it. Inadequacy of supply can be equally troublesome in the region, as the 1961-66 drought in the Northeast proved once more. Water problems and their abatement or solution here are comparable in their diversity to the diversity in climate, economy, and cultural heritage in this region of from Maine to the Virgin Islands. Results of some of the water investigations of the U.S. Geological Survey in the Atlantic coast region are given below.

### NEW ENGLAND

#### Ground-water resources of the Ashuelot River basin, New Hampshire

Moderate to large supplies of ground water in the Ashuelot River valley, in southwestern New Hampshire, are available from stratified glacial drift of



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

sand and gravel interbedded with or covered by finer lacustrine deposits, according to H. A. Whitcomb. Locally, deposits of saturated, medium to coarse sand and gravel are more than 150 feet thick. Deltaic deposits of sand and gravel at junctions with major tributaries also are potential sources of moderate supplies of water. Adequate water for domestic use can be obtained from most wells in till or bedrock. Ground-water seepage from stratified glacial drift underlying only about 10 percent of the basin, or about 40 sq mi, contributes about 1.4 mgd per sq mi to stream discharge. Some of this potential seepage could be intercepted by wells. The ground water is generally suitable for most uses, although iron and manganese are a problem in places.

#### **Ground-water resources of the middle Merrimack River basin, New Hampshire**

A preliminary survey of the Merrimack River valley between Manchester and Concord, by H. A. Whitcomb, indicated that moderate to large quantities of ground water can be developed from stratified sand and gravel in the Merrimack Valley and its tributary valleys—Suncook, Contoocook, and Piscataquog. Several wells in the Merrimack Valley reportedly yield 0.5 to 1 mgd. Two wells in the Suncook River valley, reportedly, are each capable of yielding 0.5 mgd. High-capacity wells in these two valleys usually are less than 50 feet deep and penetrate from 25 to 40 feet of saturated material. The most productive water-bearing zones are thin lenses of coarse sand and gravel, generally interbedded with or buried beneath fine-grained lake deposits. Conditions are probably similar along the Contoocook and Piscataquog. Data indicate that the chemical quality of the water is generally suitable for most purposes; however, excessive iron and manganese may restrict its use in some areas.

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

The Barre-Montpelier area in north-central Vermont has several places suitable for testing for large ground-water supplies, according to A. L. Hodges, Jr. Water-bearing beds of sand and gravel are thick along the Winooski River in East Montpelier and in Middlesex. In the town of Barre, test drilling indicated favorable conditions along Stevens Branch and Jail Branch and a possible buried channel northward from Barre City to East Montpelier. The valley of Stevens Brook also has good potential aquifers in the town of Williamstown. Ground-water conditions are favorable along the Dog River on the west margin of the Barre-Montpelier area, especially in the towns of Northfield and Berlin

and particularly between Riverton and Montpelier Junction.

#### **Ground-water resources of the White River Junction area, Vermont**

The White River Junction area in east-central Vermont is predominantly composed of bedrock and glacial-till upland dissected by several major stream valleys. A. L. Hodges, Jr., stated that favorable areas for development of substantial ground-water supplies are restricted to sand and gravel in the unconsolidated glacial drift and overlying river alluvium.

The Connecticut River valley on the east margin of the area has potential aquifers in the vicinity of both Wilder and Hartland. The White River is generally incised in bedrock, and ground-water potential is poor except in a few small areas. The Ottauquechee River valley is favorable for ground-water development, particularly between Queechee and Taftsville. Thick deposits of water-bearing sand and gravel between Hartland and Hartland Four Corners in the valley of Lulls Brook may yield much water to wells.

#### **Water resources of the Deerfield-Hoosic River basins, Massachusetts**

Analysis of precipitation-runoff data in the Deerfield River basin in northwestern Massachusetts by F. B. Gay showed a difference of 19.8 inches between the median annual precipitation of 45.2 inches and the median annual runoff of 25.4 inches during the period 1929–68. Median annual precipitation and runoff range from 42 to 50 inches and from 20 to 30 inches, respectively, between altitudes of 140 and 2,700 feet. Regionalization of streamflow records are restricted to median annual flows because of extensive regulation of the Deerfield River for electric power production.

Reconnaissance geologic mapping by L. G. Toler and B. P. Hansen and seismic work by private contractors showed the Hoosic River valley to be underlain by as much as 350 feet of unconsolidated material, which constitutes the principal aquifer of the basin. Water from sand and gravel beds underlying fine-grained glaciolacustrine material supplies several towns and industries.

#### **Water resources of the Neponset-Weymouth River basins**

The water resources of the Neponset and Weymouth River basins on the southern suburban fringe of Boston are subject to the increasing stresses and environmental changes of population growth. R. A. Brackley, W. B. Fleck, and W. R. Meyer state that pumpage within the basins for municipal water supplies has increased from about 3 billion gallons per year in the early 1940's to about 7 billion gallons per year in the mid 1960's.

Streamflow has been reduced near three pumping centers, and similar reductions are likely elsewhere. Thus, the close relation of surface water and ground water must be considered when large additional water supplies are needed in some places.

Since the mid 1950's, the chloride content of water from municipal wells has generally increased, presumably from increased waste disposal and highway salting. From 1940 to 1956 the median chloride content rose only slightly, from 6 to 9 mg/l; however, from 1956 to 1968 the median content increased to 26 mg/l, and water from two municipal wells now has a median chloride content of 136 mg/l. Although the present chloride content is well below the recommended limit of 250 mg/l set by the U.S. Public Health Service in 1962, the upward trend is unmistakable. The chemical quality of both surface and ground waters is highly variable, reflecting variations in geologic environment and localized disposals of waste. About half the aquifers (areally) contain water that is classed as excessive in manganese, more than 0.05 mg/l, and iron is excessive locally, more than 0.3 mg/l.

The areal distribution of precipitation (about 46 inches annually) is fairly uniform, and annual runoff is about 23 inches. The low flow of unregulated streams is highly variable, reflecting diversion by pumping wells and differences in geologic environment.

Analysis of precipitation data for the water years 1903-67 from gages at Milton and East Walpole indicates that the use of average monthly precipitation as an index of normal precipitation may not be valid, at least in this area. The median monthly precipitation invariably was lower than the respective average. Variation was maximum, as much as 1.03 inches, for the summer months.

Transmissivity of the five more or less separate sand and gravel aquifers, locally interbedded with silt and clay, ranges from 10,000 to 50,000 gpd per ft but locally may exceed 100,000 gpd per ft. The potential sustained ground-water yield is approximately 100 mgd, five times the current draft of about 20 mgd, most of which is diverted out of the basins through sewers. No evidence of permanent lowering of the water table by pumping is indicated.

#### **Water resources of the Charles River basin, Massachusetts**

According to E. H. Walker, W. W. Caswell, and S. W. Wandle, Jr., the principal water-bearing formation in the basin of the Charles River consists of sand and gravel deposited at and near the ice front during the melting of the last ice sheet. Such deposits are numerous but scattered; few are as large areally as half a square mile.

Water from parts of the Charles River and its tributaries has increased in sodium content as well as in potash, chloride, and compounds of nitrogen and phosphorous. Evidence from a few samples suggests that the dissolved-solids content of the lower part of the Charles River has probably increased 50 percent in the last 10 years.

#### **Water resources of the Taunton River basin, Massachusetts**

Runoff from the 528 sq mi drainage basin of the Taunton River, as reported by J. R. Williams, D. F. Farrell, and R. E. Willey, has averaged 220 billion gallons per year during the period 1931-65. Abundant off-stream storage in swamps and ponds stabilizes the runoff in the main stem and limits major flooding to the steeper, narrower tributary valleys. Of the 50 ponds larger than 10 acres, 7 are used for municipal water supplies. Diversions from surface-water sources in 1968 totaled 178 billion gallons, of which 154 billion gallons of fresh river and salty estuary water was used by electric utilities for cooling. At least 69 billion gallons per year (190 mgd) of the average annual streamflow is derived from ground-water seepage from stratified glacial drift, the principal ground-water reservoir.

Development of the 190 mgd from the stratified drift by wells is limited by the distribution of the 90 areas where the drift is capable of yielding the 300 gpm or more per well required by municipalities and industry. Most of the thick stratified drift has been deposited in preglacial valleys carved in bedrock; some of the drift in these valleys is as thick as 216 feet. About 4.3 billion gallons was pumped from these deposits in 1967.

The older underlying bedrock is a significant secondary aquifer for small supplies of water. The yield of bedrock wells was about 0.2 billion gallons in 1967.

Both surface water and ground water is generally soft, acid to slightly acid, and low in dissolved solids. Although it meets recommended limits of the U.S. Public Health Service in many respects, iron, manganese, and color content of most streams exceed these limits. Most stream water would need to be treated for use as a public supply. Temperature of ground water averages 50.3°F. and ranges from 45° to 54°F. Chloride content of most water has increased, apparently because of increase in waste effluent and from drainage of heavily salted highways and streets.

#### **Water resources of the Connecticut River basin, Connecticut**

A thick, coarse-grained, stratified-drift aquifer flanking the Connecticut River basin at the south end can supply much ground water, according to R. B. Ryder, D. A. Olin, and L. A. Weiss. One well tapping this



aquifer where it is 140 feet thick yields 87 gpm per ft of drawdown.

The areal variation of hardness and the distribution of sulfate and sodium in water from wells tapping Upper Triassic sandstone and shale were shown on maps. The mapping was based on more than 150 chemical analyses.

About 8 percent of the land in the basin is under cultivation, much of it in shade-grown tobacco, a crop requiring nitrate-rich fertilizers. Considerable fertilizer is flushed to streams during direct runoff, depending on time of application. As an example, on March 26, 1968, 456 tons of nitrate, or about 0.4 tons per sq mi, was added to the Connecticut River in the 30-mile reach below the Massachusetts border.

Analysis of data from the tributary 98.4-sq-mi Scan-tic River subbasin indicated that the suspended sediment load of the river decreased steadily from 1958 to 1968, reflecting the change in land use from agricultural to suburban-residential.

#### **Ground-water resources of the Branch River area, Rhode Island**

The principal aquifer of the Branch River area, Rhode Island, is glacial drift, a fill of medium to coarse sand and gravel in preglacial valleys. Transmissivity of the aquifer, estimated by H. E. Johnston and D. C. Dickerman from specific-capacity data and lithologic logs of wells, ranged from 2,500 to 110,000 gpd per ft. Average permeability in 20 localities, using data from 103 wells, ranged from 200 to 1,700 gpd per sq ft; median permeability was 1,000. A transmissivity map indicates transmissivity belts, 1,000 to 2,000 feet wide, of 40,000 to 60,000 gpd per ft along the axes of main segments of preglacial valleys. These belts correspond approximately to areas where saturated thickness is 40 to 60 feet.

Yields of 150 to 500 gpm have been developed from large-diameter wells in this aquifer in a few places; yields of 200 to 700 gpm could be obtained in several other places, as yet undeveloped. Five ground-water reservoirs are capable of sustained yields of 1 to 2 mgd during exceptionally dry years; another, in the lower part of the Branch River basin, is capable of a sustained yield of 5 mgd.

#### **NEW YORK**

##### **Appraisal of hydrologic conditions in Suffolk County, Long Island**

H. M. Jensen reported that test holes drilled in Suffolk County penetrate thick (more than 600 feet in places) glaciofluvial and glaciolacustrine deposits in ice-scoured channels that trend predominantly north-

south. According to Jensen, determining the degree of interconnection of the saturated glacial deposits and the underlying and abutting Cretaceous deposits is an important element in the hydrologic appraisal of Suffolk County.

##### **Status of salt-water wedge, Long Island**

Philip Cohen and G. E. Kimmel (p. D281-D286) reported that analyses of water from wells in southern Nassau and southeastern Queens Counties showed little, if any, regional movement of a wedge of salty ground water underlying the nearshore area near the base of the Magothy aquifer during the period 1963-69. Salty water in the Lloyd aquifer, which underlies the Magothy aquifer along the south shore of Nassau County, also showed no movement. Pumpage in Nassau County increased from 150 to 173 mgd between 1963 and 1969, and water levels in the Magothy have declined about 1 foot in nearshore areas. Some local increases in chloride content were noted in water from wells near heavily pumped areas.

#### **NEW JERSEY**

##### **Geohydrology of Camden County**

Aquifers in Camden County were mapped by G. M. Farlekas, Bronius Nemickas, and H. E. Gill by analyzing more than 100 geophysical logs. The major ground-water units are (1) the aquifer system in the Potomac Group and Raritan and Magothy Formations, (2) the aquifer in the Cohansey Sand, (3) the aquifer in the Kirkwood Formation, and (4) the aquifer in the Mount Laurel Sand-Wenonah Formation. The minor ground-water units are (1) the aquifer in the English-town Formation and (2) the aquifer in the Woodbury Clay-Merchantville Formation. Both major and minor ground-water units were delineated, and their hydrologic characteristics were determined.

The prepumping potentiometric heads were obtained for all the aquifers. In general, the younger the aquifers, the higher the head. The head of the oldest aquifer, the Potomac Group and Raritan and Magothy Formations, was at or near sea level. Prepumping potentiometric-head maps were constructed for several of the aquifers.

Head-decline maps, based on the prepumping potentiometric head, were prepared for the aquifer system in the Potomac Group and Raritan and Magothy Formations. Head-decline maps were also constructed to obtain the difference in head between 1956 and 1968. The decline in head for the 12-year period was as great as the decline for the first 60 years. As of 1968, the potentiometric level in wells in Camden County had declined more than 100 feet.

## PENNSYLVANIA

### Fracture traces in the Catskill Formation

The incidence of high-yielding wells inventoried by J. R. Hollowell and H. E. Koester in the Dalton quadrangle, Lackawanna County, northeastern Pennsylvania, is associated directly with extensive fractures in the Catskill Formation. Of wells yielding 40 gpm or more, 23 of 30 were found to penetrate fracture traces, and many were on or near the intersection of two or more fracture traces. The fracture system in the Dalton quadrangle is well developed; some traces are as long as 4 miles. Fracture traces are less abundant elsewhere in the county.

### Potential aquifer discovered in Crawford County

According to G. R. Schiner, a third large outwash deposit was discovered by test drilling at the confluence of a tributary with a major glacial drainageway—French Creek valley, in Crawford County, northwestern Pennsylvania. Two other similar deposits are capable of high yields to wells. The deposit consists of 46 feet of sand and gravel overlain by 64 feet of fine-grained lacustrine and fluvial sediments and underlain by 290 feet of similar fine-grained sediments, which, in turn, rest upon bedrock.

A short test indicated that the aquifer should yield as much as 1,000 gpm. The water has a dissolved-solids content of 220 mg/l, a hardness of 170 mg/l, and an iron content of 1.0 mg/l.

### Quality of Monongahela River water improving

Large areas in the Monongahela River basin are significantly affected by acid mine drainage. Overflow of acid water from many abandoned mines, caused by heavy precipitation, and natural leakage continue to threaten pollution of streams and death to fish and other fresh-water organisms. During the 1960's, however, water quality of the Monongahela in Pennsylvania improved progressively, according to E. F. McCarren. Improvement can be traced directly to Pennsylvania's Clean Streams program and the cooperation of municipalities and industries. Also, the treatment of sewage and industrial wastes in the Pittsburgh area has been stepped up as a result of the operation of a new multimillion dollar collection and treatment facility.

## MARYLAND

### Traveltime and concentration attenuation of a soluble dye in the Monocacy River

Graphs developed by K. R. Taylor<sup>45</sup> from three time-of-travel studies on the Monocacy River, Fred-

<sup>45</sup> Taylor, K. R., 1970, Traveltime and concentration attenuation of a soluble dye in the Monocacy River, Maryland: Maryland Geol. Survey Inf. Circ. [In press]

erick County, northwestern Maryland, will enable water users to predict, over a wide range of flows, not only traveltimes but also peak concentrations of soluble contaminants spilled in the river. Graphs show that the peak concentration resulting from a contaminant spill 28 miles above the Frederick water intakes at an index flow of 100 cfs is only 20 percent greater than that at an index flow of 400 cfs. The time required for the contaminant cloud to pass the water intakes, however, is more than 400 percent longer at the lower index flow. At an index flow of 100 cfs, graphs also show that more than 30 days will be required to flush the 57-mile-long river of a contaminant spilled at the Pennsylvania State line.

### Exploring a paleochannel near Salisbury

A buried gravel-filled valley near Salisbury, southeastern Maryland, was mapped by J. M. Weigle by a combination of methods. Test holes were drilled with a power auger and were gamma-logged through the hollow drill stem.

The auger was capable of drilling to the flanks but not to the bottom of the buried valley. It was possible, thus, to outline the valley by bracketing. Thus bracketed, the deep central part was then explored by conventional drilling methods. The technique proved to be flexible, rapid, and economical.

## VIRGINIA

### Ground water in the Franklin area

According to O. J. Cosner, G. A. Brown, and J. L. Chisholm, fifteen multiscreened industrial wells at Franklin, southeastern Virginia, yield 30 to 40 million gallons of water per day from Lower Cretaceous sand beds. Water-level recovery was measured in four observation wells during the 1969 Labor Day shutdown. The aquifer constants obtained from this test varied widely, indicating that the Lower Cretaceous sand beds constitute a multiple aquifer and that short-term aquifer tests in this area may be considerably in error.

Chemical analyses indicate that the ground water has a low mineral content; however, some rather striking differences in mineral content were noted in water from different wells. For example, chloride ranged from 4.4 to 32 mg/l, sodium from 90 to 162 mg/l, and bicarbonate from 215 to 364 mg/l. Such differences strengthen the conclusion that the Lower Cretaceous sand beds constitute a complex, multiple aquifer.

## NORTH CAROLINA

### North Carolina water-quality data analyzed

H. B. Wilder and L. J. Slack, in analyzing stream-quality data collected in North Carolina during the



period 1943-67, concluded that, although the quality is generally very good, the effects of man's activities are more significant than previously realized. Natural dissolved-solids content was estimated by analysis of samples from small pristine streams. This was compared with dissolved-solids content of water from streams draining more highly populated areas. On this basis, dissolved-solids content of the major rivers draining into the ocean seems to be derived about 45 percent from natural sources and about 55 percent from man's activities.

At the three stations that were operated for a full water-year in 1943 and in 1966, the average chloride concentration per unit of discharge approximately doubled during the 23-year period.

### **SOUTH CAROLINA**

#### **Aragonite water in South Carolina**

A precipitate causing milky water in a well at Kingstree, Williamsburg County, southern South Carolina, has recently been identified as aragonite by P. W. Johnson. Precipitation is probably caused by release of pressure in artesian aquifers where the water is saturated with CO<sub>2</sub>. Cloudy or milky ground water has been a problem in many places in the Coastal Plains of South Carolina, but its cause has never before been identified.

The problem is serious because large wells have been abandoned or their use curtailed because of the precipitate.

The city well at Kingstree has provided most of the data. A sample of its water analyzed by X-ray diffraction indicates that more than 98 percent of the residue is aragonite. Point samples of water in the well bore have been taken, and resistivity logging and other techniques are currently being applied.

Data and samples from other similar wells are being collected. Historical data pertaining to these wells are meager, and correlation is difficult, but present data indicate that the water is from a zone 300 to 400 feet below the surface at Kingstree in marine sediments of Late Cretaceous age.

#### **Deep well near Charleston**

The deepest well in the Charleston area, total depth 2,292 feet, was begun in January 1969 and completed in March, according to G. E. Siple. The first cores of Cretaceous sediments in the coastal area were recovered—with the possible exception of cores recovered from a deep well in Beaufort County. Hitherto unrecognized nonmarine deposits of pre-Austin (and probably Early Cretaceous) age were penetrated at 2,215 feet below

sea level. The pore water in the penetrated clay was fresh.

Coastal Plain streams that receive most of their recharge from ground water, and sediment-laden extended consequent streams can be differentiated on Apollo 9 color photographs. Other significant geomorphic features, such as Carolina bays, however, are poorly defined.

### **GEORGIA**

#### **Large supplies of ground water of good quality, northwestern Georgia**

During a study of the availability of water supplies in northwestern Georgia, C. W. Cressler learned that the upper part of the Knox Group (Upper Cambrian and Lower Ordovician) will yield 1,000 gpm and more to properly located wells. Conditions favoring high-yielding wells occur at numerous places in the upper Knox of northwestern Georgia, and it seems likely that this source may attract industries requiring water of good quality.

#### **Hydrologic studies in the North Newport River area**

R. G. Grantham's water-quality studies of the North Newport River are continuing in order to detect significant changes in water quality due to injection of an industrial effluent. High runoff this year resulted in no appreciable effluent buildup, and specific conductance throughout the estuary dropped to record lows for the 3-year study period. However, the water level in the principal artesian aquifer has declined 6 feet in the vicinity because of the 9.5 mgd pumpage for the industrial water supply.

#### **Transmissivity markedly different in northern and southern Colquitt County**

The investigation of the ground-water resources of Colquitt County, southwestern Georgia, by E. A. Zimmerman, indicated that ground water is adequate for all present uses as well as for a considerable expansion of supplemental irrigation.

Aquifer tests suggested that the water-bearing properties of the principal aquifer in the northern part of the county differ markedly from those in the southern part. Transmissivity in the southern part exceeds 1,000,000 gpd per ft but is less than 100,000 gpd per ft in the northwestern part. The difference is tentatively attributed to facies changes in the aquifer.

### **FLORIDA**

#### **Potable water in Floridan aquifer**

A contour map prepared by Howard Klein shows the approximate depth below the land surface to the bottom of the zone of potable water in the Floridan aquifer.

fer throughout Florida. The prominent features of the map are the thick section of potable water in central and northern Florida, which corresponds to the prime recharge area for the aquifer, and the thin potable section in the upper St. Johns River valley, where upward leakage along fault zones has lowered pressure and permitted vertical movement of saline water from deep parts of the aquifer. The map should assist water managers in decisions concerning the future use of the aquifer.

#### **Saline water found in Walton County aquifer**

Water in Walton County, in the Florida panhandle, is generally available in abundant quantities in the upper zone of the Floridan aquifer (Chickasawhay Limestone and Tampa Formation). The water is of excellent quality except in about 20 square miles adjacent to Choctawhatchee Bay, where chloride content may exceed 4,000 mg/l, according to C. A. Pascale. Saline water from the lower zone of the Floridan aquifer (Ocala Limestone) seems to be mixing with fresh water in the upper zone. The head is greater in the lower zone, and the saline water may be moving upward through fault zones or poorly constructed wells.

#### **Floridan aquifer recharged in Lake Wales ridge area**

The relatively high Lake Wales ridge in Lake County, central Florida, has nearly no runoff. Permeable sand and clayey sand beds 50 to 200 feet thick underlie the ridge. These beds overlie the Eocene limestone of the Floridan aquifer. In an area that normally receives 52 inches of rainfall per year and in 1969 received almost 64 inches, the water table is as deep as 200 feet below the land surface and conforms much more closely to the regional potentiometric surface of the Floridan aquifer than to local topography. The water table is from 1 to 3 feet above the potentiometric surface of the Floridan aquifer. Pumping effects from deep wells open only to the Floridan aquifer have been observed in observation wells open only to the water-table aquifer, which indicates a high degree of connection. Thus, the Lake Wales ridge, with its small runoff and its high infiltration capacity, is an area of recharge to the Floridan aquifer, according to D. D. Knochenmus.

#### **Quality of water in upper part of the St. Johns River basin**

Results obtained to date in an investigation, by D. A. Goolsby and B. F. McPherson, of approximately 2,000 sq mi in the upper St. Johns River basin, central-eastern Florida, indicate that dissolved oxygen is naturally low in the upper part of the basin. The lowest value for dissolved oxygen in the river, 1.0 mg/l, was

observed after heavy rain in the early fall and evidently resulted from decomposition of organic material on the flood plain and in the marshes. Water in a new reservoir contained less than 0.3 mg/l dissolved oxygen after the heavy rain. The natural concentration of dissolved phosphorus was as much as 0.4 mg/l, as  $\text{PO}_4$ , and the nitrogen concentration was as much as 1.2 mg/l. Most of the nitrogen is organic. Early results indicate that the river and lake sediments are very high in carbon, nitrogen, and phosphorus. Some sediment samples contained as much as 40 percent carbon, 2.5 percent nitrogen, and 0.05 percent phosphorus.

#### **Floridan aquifer pumped heavily in the Bartow area**

Transmissivity of the Floridan aquifer in Lakeland, Polk County, in central Florida, is about 750,000 gpd per ft, as determined from a controlled pumping test by A. F. Roberston. In the Bartow area, where industrial pumpage is great, water levels were 40 feet lower in 1969 than they were in 1959. North of Lakeland, away from the area of concentrated pumping, levels have not changed appreciably. Analyses of water samples during 1959-69 show a deterioration of water quality only in the area of heavy pumping, suggesting that the quality change is related to the lowering of water levels.

#### **Potential recharge to the Floridan aquifer in Pinellas County**

A shallow aquifer consisting of fine-grained sand underlies the Clearwater-Dunedin area, central-western Florida, and is a potential source of recharge to the underlying Floridan aquifer, according to R. N. Cherry.

Natural recharge is impeded by a clay layer 20 to 60 feet thick that effectively separates the two aquifers. Test sites are being constructed to determine the feasibility of installing connector wells through the clay. The sand aquifer is as thick as 60 feet, and the dissolved-solids content of the water is generally less than 150 mg/l. The potentiometric surface of the shallow aquifer is 10 to 50 feet above that of the Floridan aquifer.

#### **Dissolved solids low during high streamflow in De Soto and Hardee Counties**

Specific conductance determined by W. E. Wilson at 66 sites in the Peace River basin, De Soto and Hardee Counties, indicated that dissolved-solids content of the streams is generally low during periods of high stream flow. Specific conductance was less than 100  $\mu\text{mhos}$  at 32 sites and more than 200  $\mu\text{mhos}$  at only 11 sites; highest was 490  $\mu\text{mhos}$ . The specific conductance of the Peace River, affected by upstream phosphate mining, was 320  $\mu\text{mhos}$  where it enters Hardee County. Down-

stream, the river was progressively diluted by tributary streams, and, near the southern boundary of De Soto County, specific conductance was 100  $\mu$ mhos.

#### **Shallow aquifer contamination by saline irrigation water in Indian River County**

Although water relatively high in chloride (300 to 1,000 mg/l), is generally obtained from the Floridan aquifer in Indian River County, central-eastern Florida, the water is used extensively for irrigation because of the large yields from the free-flowing wells and the tolerance of the principal crop (citrus) to chloride. The major source of potable water in the county, on the other hand, is a shallow, sand and shell aquifer underlying the eastern half of the county. L. J. Crain reported that large areas of the shallow aquifer are being contaminated by irrigation water from the Floridan aquifer. In base-flow studies of the canal system draining the shallow aquifer, a direct correlation exists between the proportion of the drainage areas irrigated and the chloride content of the canal water.

As the population grows, more of the shallow aquifer is being developed for public water supplies. Also, increasing acreage overlying the shallow aquifer is being irrigated with water from the Floridan aquifer. Both of these factors are conducive to bringing about problems in the county.

#### **Limited availability of water from canals and shallow sediments in St. Lucie County**

Water in canals and shallow sediments in St. Lucie County, northeast of Lake Okeechobee, is insufficient for citrus irrigation during extended dry periods, according to a study by H. W. Bearden. Quantitative seepage studies along the primary canals showed poor interconnection between the canals and the shallow sediments. The maximum ground-water pickup was about 2 cfs per mi. High gradients on water-level contour maps and water-level profiles show that the shallow sediments are of low permeability. From aquifer tests it is estimated that the yield of wells 6 inches in diameter or larger, 40 to 100 feet deep, would be 100 to 200 gpm.

#### **Changes in quality of water in Lake Okeechobee evaluated**

An evaluation, by B. F. Joyner, of data collected in a 1-year study of Lake Okeechobee indicated that the lake is in a "young eutrophic" condition, based on contained algae species. Phytoplankton concentration from all locations was less than 50 cells/ml in January and August 1969 and January 1970. A maximum of 4,600 cells/ml occurred in May in the western part of the lake. The characteristic phytoplanktonic organism pres-

ent was *Pediastrum simplex*, a green algae typical of very young eutrophic lakes.

Nitrogen and phosphorus concentrations were not excessively high. Nitrate ( $\text{NO}_3$ ) was highest in January (1.4 mg/l) and lowest in August (0.1 mg/l). Organic nitrogen (N) was 0.9 mg/l in January and 1.2 mg/l at the height of the growing season in May. Nitrite ( $\text{NO}_2$ ) and ammonia ( $\text{NH}_4$ ) were generally less than 0.05 mg/l, and total phosphate ( $\text{PO}_4$ ) averaged about 0.07 mg/l. Average dissolved-solids content of water in the lake has increased from 190 mg/l in 1941 to 280 mg/l in 1969, with notable increases in calcium, magnesium, sodium, chloride, sulfate, and bicarbonate. However, flushing from abnormally high runoff caused a decrease in dissolved solids from 340 mg/l in January 1969 to 245 mg/l in January 1970.

Lake-water temperature ranged from 10°C to 30°C. The dissolved oxygen concentration generally was near saturation, ranging from 6.8 to 11.2 mg/l.

Trace quantities of DDT, usually less than 0.1  $\mu$ g/l, occasionally occurred in the lake water. Concentrations of DDT as high as 2,900  $\mu$ g/kg, however, were detected in the bottom sediments.

#### **Shallow aquifer in eastern Charlotte County has public-supply potential**

Horace Sutcliffe, Jr., and Geronia Bowman delineated, by test drilling, a shallow limestone and shell aquifer that contains water which could be treated and used for public supply. The aquifer yields 600 gallons per minute to irrigation wells 30 to 100 feet deep.

#### **Water-quality effects in Loxahatchee National Wildlife Refuge**

A. L. Higer, M. C. Kolipinski, and Antonio Jurado stated that the concentration of five constituents (nitrate, sulfate, calcium, dissolved solids, and iron) was considerably lower in the marshlands of Loxahatchee National Wildlife Refuge than in the canals furnishing water to the marshlands. It appears that the marshland plants are assimilating the constituents.

#### **Sea-water intrusion into the Hallandale and Dania areas**

The extent of sea-water intrusion into the highly permeable Biscayne aquifer in the Hallandale and Dania areas, north of Miami Beach, has been established from data collected during the drilling of salinity test wells in both cities, according to H. W. Bearden. Saline water (1,000 mg/l) was detected 0.4 mile east of the Hallandale municipal water plant and 0.35 mile east and less than 300 feet west of the Dania municipal water plant. Intrusion in both areas is chiefly caused by long-term drainage activities and

heavy pumping of ground water. Intrusion in the Dania area is complicated by a tidal canal 0.25 mile west of the water plant.

#### **Water management and water supply, Fort Lauderdale**

Hydrologic data collected in the vicinity of a controlled feeder canal nearing completion indicated that recharge from the canal is effective in moderating drawdowns and retarding sea-water intrusion in the aquifer in the Fort Lauderdale Prospect well-field area. The effectiveness of the canal in this respect will be estimated more accurately during the dry part of the year (May-August) after completion of the canal.

The use of water from the canal system to replenish ground-water supplies emphasizes the importance of contaminants in the canal waters. Sampling by H. J. McCoy and C. B. Sherwood in canals adjacent to Fort Lauderdale's Dixie and Prospect well fields indicated low-level but increasing contamination by pesticides and by effluent from sewage-treatment plants.

#### **Effects of drainage system on water resources, western Collier County**

Discharge was measured during wet and dry periods at more than a dozen sites in controlled canals of a large drainage system inland from the coastal ridge in western Collier County. Total discharge to the gulf during the dry period was 106 cfs and was 1,126 cfs during the wet period. Howard Klein and H. J. McCoy will use these data along with test-hole data to determine if the drainage system can be utilized to sustain recharge to new well fields along the controlled canals.

#### **Effect of grass cutting in the Everglades**

The grass was cut below several control structures in the flat (slope of about 2 inches per mile) Everglades in an effort to increase the discharge. The 200 by 1,500-foot swaths were cut primarily through a widespread sedge, commonly called sawgrass. Analysis of a series of discharge measurements by J. H. Hartwell showed that flow increased about 15 percent but that the increase persisted for less than a month. Thereafter, a decrease in discharge at a given stage was observed. The effect of the mowing was found to be small and only temporary.

#### **Electric-analog study of Biscayne aquifer continues**

C. A. Appel reported that the analog study of the Biscayne aquifer is providing a better understanding of the effect of operating canal control structures under various operating rules.

#### **Hydrology of Buttonwood Canal area**

Buttonwood Canal extends from Florida Bay to Coot Bay in southernmost Florida. The canal permits

salt water to enter Coot Bay and to render it saline the year round. Before the opening of the canal, the water in the Bay was brackish, in varying degrees, during the wet season owing to the influx of fresh water. J. H. Hartwell estimated fresh-water runoff of only 10,000 acre-feet through the Buttonwood Canal for 1967—only about 2 percent of that entering Everglades National Park from the north.

#### **Temporary salt-water control in Canal 111**

Studies in the Canal 111 area in southernmost Dade County indicated that removal of a plug in the canal near the coast could endanger part of Everglades National Park and accelerate salt-water encroachment. F. W. Meyer and J. E. Hull report that the plug diverted flows exceeding 1,500 cfs overland into Everglades National Park without significantly affecting the head in the upper reaches of the canal. In early 1969, the plug was replaced by an earthen structure (S-197) with three gated culverts. Releases through S-197 not only lessened the overland flow through the gaps but caused some rerouting of the flow into the canal through the westernmost gaps. During a release on October 24, 1969, salt-water migration upstream was caused by a wind-blown tide.

#### **Sea-water intrusion, Dade County**

Continuing studies of sea-water intrusion by F. W. Meyer and J. E. Hull indicate a steady improvement in operations of salinity controls in Dade County. Ground water in the vicinity of the North Miami well field has progressively freshened since 1962, as a result of the salinity control in Biscayne Canal. Salinity problems in southern Dade County are expected to decrease as a result of improved operation of the recently completed network of controlled canals.

### **PUERTO RICO**

#### **Water in the Guayama area**

The Guayama area, on the south coast, is composed of about 12 sq mi of coastal alluvial plain and 10 sq mi of mountainous terrain of the upper Rio Guamani basin. The principal aquifer is along the coastal plain in the Guayama fan and Guamani fan areas.

Hydrologic data collected by J. R. Diaz from January to June 1969 indicated that the thickness of the alluvial aquifer ranges from 40 to 100 feet; sand and gravel formed by Rio Guamani are the principal water-bearing formations. Transmissivity in the Guamani-fan alluvial aquifer ranges from 9,000 to 120,000 gpd per ft. In the Guayama fan, average transmissivity is about 12,000 gpd per ft.

Rainfall and return flow from irrigation are the

principal sources of recharge to the Guayama area. Streamflow recharge is limited to a thin strip along the Rio Guamani.

Estimated increase in ground-water storage for the 6-month period of study was 1,600 acre-ft. Pumpage was 1,200 acre-ft.

#### **Water in Yabucoa Valley**

R. B. Anders reported that the principal aquifer in the Yabucoa Valley is alluvium, as thick as 200 feet, composed of clay, silt, and sand. The deposition of sand zones in the alluvium apparently was controlled by ridges of diorite, now buried, extending into the valley.

The valley is drained by several streams; Rio Guayanes is the largest. Stream discharge to the sea at the end of the rainy season in December 1968 was about 60 cfs, and at the end of the dry season in April 1969 the discharge was about 30 cfs. Ground-water discharge to the streams during these periods was about 20 cfs and 5 cfs, respectively. Data indicate much of the fluctuation of ground-water discharge to the streams is caused by transpiration by sugarcane.

About 35,000 acre-ft of ground water is in transient storage in the alluvium. The potential yield of the alluvium is estimated to be 15 mgd. Present use is about 2 mgd. Both surface water and ground water are suitable for domestic, agricultural, and industrial uses.

### **MIDCONTINENT REGION**

Emphasis of water-resources programs in the mid-continent region is increasingly directed to collection and analysis of hydrologic information that is essential to sound water development and management decisions. Improvement of water data systems to increase efficiency and productivity of data collection activities was initiated by a streamflow network evaluation in fiscal year 1970. Ground work has also begun for similar evaluation of coverage and accuracy requirements of a water-quality observation network that is fully responsive to current and future information needs. Reshaping of data programs and reprogramming of work activities is in response to a widespread public concern for slowing and reversing the accelerating deterioration of the natural environment.

Other investigations include water-resources appraisals, studies related to specific problems of water-supply deficiency, water quality, and flooding, and hydrologic information needs for recreational activities and metropolitan area planning. Results of appraisal studies provide information on new sources or previously undeveloped sources of ground water that can alleviate current water shortages, or can be used con-

junctively with surface-water supplies in long-range planning for optimum use of the total water resource. Manageability of ground water was emphasized in initial planning of a new study of Ohio River basin, a region of abundant water supplies, but one of numerous problems related to management, optimum use, and distribution of its water resources. Concentration of population in metropolitan areas produces new and different problems of water-oriented planning—water supply, storm runoff, liquid and solid waste disposal, and recreational facilities. To meet the challenge of preserving the quality of the environment of the metropolitan area and to assure safe and adequate water supplies for the future, studies are in progress in the Minneapolis - St. Paul, Minn., St. Louis, Mo., and Huntsville, Ala. areas.

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

### **INTERSTATE STUDIES**

#### **Geohydrology of the lower formations of the Claiborne Group**

Maps of sand percentage, sand-unit thickness, estimated coefficient of transmissivity and dissolved-solids content of water of the Reklaw and Queen City Formations of Texas and the Cane River Formation or equivalents of Arkansas, Louisiana, and Mississippi have been completed. J. N. Payne reported good correlation between lithologic variation and sand-unit thickness and the hydraulic characteristics of the aquifers and the chemical quality of the waters.

Stiff-type diagrams of chemical analyses of waters from the Queen City Sand show a high degree of variability in quality of water contained in sands at higher altitudes (sea level to 500 feet above sea level) as contrasted with waters from sand at lower altitudes (sea level to 3,000 feet below sea level). Waters from the sands at the higher altitudes contain relatively high concentrations of calcium, magnesium, sulfate and chloride. Waters from the sands at the lower altitudes are predominantly of the sodium bicarbonate type.

### **MINNESOTA**

#### **New sources of ground water for irrigation**

Glacial outwash in the Little Falls area, Morrison County, was reported by J. O. Helgesen to be a potential source of water for irrigation. Saturated thickness of the aquifer in much of the area ranges from less than 30 feet, to about 100 feet in a long, narrow strip through the center of the area. Transmissivity exceeds 100,000 gpd per ft in much of this area of thicker deposits. Precipitation is the main source of recharge to the ground-water system, and base flow and

evapotranspiration within the area are the main methods of ground-water discharge.

H. O. Reeder (r2137) estimated that wells can be expected to yield 1,200 gpm for 30 days in the Perham area, Otter Tail County, and have drawdowns of less than two-thirds of the aquifer thickness in much of the area. Yields vary widely in short distances, however, and are expected to be as little as 300 gpm or less near the edges of the area and in the area generally east and southeast of Otter Tail Lake.

Streamflow from the area will not be depleted within the 10-year analysis period, using the permitted 6 inches of water on all the irrigable land in the outwash area. If it can be assumed that the pumpage and its effects on the streams can be distributed proportionately along the length of the streams in the area, the levels of the lakes along the streams generally will not be lowered appreciably. Because of the heterogeneity of the aquifer and other variable factors, possibly some reaches of the stream will cease to flow as full ground-water development is approached, and the levels of some lakes may decline. Lakes and ponds not connected to the streams are expected to be lowered considerably or dried up completely as pumping progresses in years to come.

If irrigation wells or other large-yield wells in the area of study are spaced a mile or more from streams and lakes, the effect on the streams of pumping ground water will be small and the lake levels will be affected very little. Water in lakes and ponds, however, is expected to approach normal levels during periods of precipitation and periods when wells are not being pumped.

#### **Water resources of river basins in Minnesota**

Studies in progress by G. F. Lindholm and J. O. Helgesen indicate the presence of several bedrock valleys filled with glacial drift deposits in the Kettle, Snake and lower St. Croix River watersheds. Dependent on the texture of the driftfill, buried valleys are areas of potentially large ground-water supplies. A buried sand and gravel aquifer in the vicinity of Mora, in the Snake River watershed, has a transmissivity of 800,000 gpd per ft.

Surficial outwash in the Kettle River watershed yields as much as 500 gpm to wells. In the Snake River watershed only small areas of outwash are capable of large yields. About one-third of the lower St. Croix watershed is covered by outwash as a part of the extensive Anoka sand plain. Test drilling indicates that saturated thickness of the outwash sands is commonly 20 to 60 feet, being thickest in the southwestern part of the area.

The drift areas are underlain by thick permeable

Precambrian sandstones that contribute significant amounts of water to the regional ground-water flow system.

Preliminary surveys of ground-water resources by W. A. Van Voast indicate that the major sources for municipal and industrial water supplies in the Cottonwood, Blue Earth, and Minnesota River basins are sandstones of Cretaceous, Ordovician, and Cambrian age, and the glacial drift sand and gravel.

Wells in sand and gravel aquifers in the glacial drift yield as much as 1,000 gpm at New Ulm. Wells in Cambrian sandstone at Blue Earth have furnished 800 gpm since 1956, and at Mankato have been tested at 2,000 gpm.

### **WISCONSIN**

#### **Ground-water augmentation of streamflow**

Investigations by R. P. Novitzki in Dane County indicated that the dissolved oxygen concentration of stream water improved significantly in response to streamflow augmentation by ground water. The study reach, just below a sewage treatment plant, had exhibited diurnal dissolved-oxygen concentrations as low as 3 mg/l, with concurrent trout kills, during the summer months. During the summer period of flow augmentation dissolved-oxygen concentrations were maintained at 7 mg/l or above. In response to this habitat improvement, significant numbers of trout moved upstream into the study reach. Habitat improvement also was indicated by an increased number of native fingerling trout in the late summer.

Maximum temperatures in the study reach are normally within the tolerance limits of trout, even critical summer periods. Consequently, temperature changes resulting from augmentation were not significant to habitat improvement.

#### **Development in a wild river area**

E. L. Oakes, S. J. Field, and L. P. Seeger found that development can take place in the eastern, unprotected one-third of the Pine-Popple River basin without affecting the western, protected two-thirds. Regional ground-water movement, as well as streamflow, is from west to east. Ground or surface water use in the unprotected zone will not affect the quality or quantity of water available in the protected zone.

Ground and surface water in the basin, although high in iron, is suitable for most purposes. Up to 500 gpm of ground water can be obtained where the saturated thickness of glacial drift is greater than 50 feet. Average flow of the Pine River at the Pine River powerplant is 420 cfs which is nearly all used for power generation. This use does not degrade the quality of the stream water.

**Water-deficient area in central Wisconsin**

E. A. Bell and M. G. Sherrill continued a search for additional sources of ground water, in a water-poor area in central Wisconsin, to satisfy increasing demands for public and industrial supplies. Moderate yields of water of generally good quality are available from glacial-outwash sand and gravel in some pre-glacial channels of bedrock. Those channels, however, are narrow and limited in extent. Contours of bedrock and configuration of deposits of sand and gravel indicate that the greatest potential source of ground water in the area, excepting the Wisconsin River valley, is northwest and northeast of Marshfield.

**Ground water in the Milwaukee River basin**

J. B. Gonthier found that three principal aquifers underlie the Milwaukee River basin. They are, in order of increasing depth, sand and gravel, dolomite, and sandstone. The dolomite and sandstone aquifers are the most important because they underlie the entire basin; whereas, the sand and gravel aquifer is highly variable in character and is located mainly in rural western and northern sections where large demands for water are not anticipated.

In response to large-scale, long-term pumping, water-table conditions will probably prevail in the sand and gravel aquifer, semi-artesian in the dolomite aquifer, and artesian in the sandstone aquifer. Transmissivity of the sand and gravel aquifer locally ranges as high as 200,000 gpd per ft. The range of estimated average transmissivity of the dolomite aquifer is from 2,000 to 10,000 gpd per ft, and of the sandstone aquifer from 3,000 to 23,800 gpd per ft.

Annual ground-water recharge in the basin is estimated to vary between 1 and 4 inches depending mainly on the character of the surficial glacial deposits. Between 1 and 3 inches of recharge may be induced, from the overlying glacial deposits, to recharge the dolomite aquifer during pumping. Recharge to the sandstone aquifer is extremely low.

The total concentration of dissolved solids in ground water from the dolomite and sandstone aquifers gradually increases toward the east in the basin. The concentration rarely exceeds 1,000 mg/l in the dolomite aquifer, but concentrations of over 6,600 mg/l were noted in the sandstone aquifer at one locality.

**MICHIGAN****Large ground-water reservoir in the Rifle River basin**

Broad sandy plains and areas having numerous topographic depressions in the headwaters of the upper Rifle River basin serve to capture precipitation, furnish excellent recharge areas, and provide the principal

source of water for streams and wells in the Rifle basin. The recharge areas are both within and beyond the basin's topographic divide. Studies by R. L. Knutilla and F. R. Twenter indicated that more than 50 sq mi of area beyond the topographic divide contributes water to the Rifle basin as ground-water inflow. Because of the expanded ground-water divide, and the nature of the glacial materials, streams retain high base-flows even during dry periods, springs are numerous, and wells flow freely—many flow under sufficient pressure to supply household needs without the use of pumps.

**Ground water in Houghton and Keweenaw Counties**

C. J. Doonan and G. E. Hendrickson reported that most wells in Houghton and Keweenaw Counties yield only enough water for a domestic supply, but a few yield several hundred gallons per minute. Bedrock aquifers supply most of the wells in Keweenaw County and about half the wells in Houghton County, but all wells yielding more than 100 gpm are in glacial deposits. The water from most wells is satisfactory for domestic use, but many wells produce water that contains troublesome amounts of iron. Water that is too salty for drinking is obtained from a few of the deeper bedrock wells. Most public supplies are obtained from wells and springs, but some are obtained from Lake Superior or from mine shafts.

**OHIO****Ground water in northern Ohio basins**

A ground-water reconnaissance study of northern Ohio basins that drain into Lake Erie showed that local buried gravel deposits and watercourse aquifers of glacial origin can yield as much as 1,500 gpm. A. C. Sedam reported, however, that much of the region's glacial cover consists of thin tills and lacustrine silts, and yields to wells are generally small. Good water supplies are available in the Silurian and Devonian carbonate rock section of northwestern Ohio where wells may yield more than 500 gpm. Mississippian and Pennsylvanian sandstone aquifers, the principal bedrock sources in northeast Ohio, may yield up to 250 gpm. Ground water is deficient in a number of areas underlain both by shale and unconsolidated materials of low permeability. Water treatment for hardness and iron content is commonly required for the region's aquifers. In some places ground water from the carbonate rock is very highly mineralized, but a number of communities are using it as their only available water source.

Studies of the carbonate rock aquifers in northwest Ohio by S. E. Norris and R. E. Fidler revealed that



wells having the highest yield, and supplying water with the lowest hydrogen sulfide content, occur in areas of structural highs associated with the north-plunging Cincinnati arch. The principal carbonate rock units of northwest Ohio, those of the Silurian-age Niagara and Cayuga Groups, dip northward into the Michigan basin at a rate of about 13 feet per mile, roughly twice that of the land surface and the piezometric surface in wells. This generally uniform structural slope is interrupted by local upwarping along the top of the Cincinnati arch, of which the main axis extends northward through Kenton, Findlay, Bowling Green, and Toledo, and a subsidiary axis extends northwest from the main structure through points in the vicinity of Wapakoneta, Celina, and Van Wert. Wells in these structurally high areas have been test pumped at rates up to 500 gpm with specific capacities of 10 to 40 gpm per ft of drawdown. By contrast, wells in intervening areas, comprising most of the northwest Ohio study area, typically yield less than 500 gpm with specific capacities of 1 to 10 gpm per ft of drawdown. Some wells in these less favorable areas yield less than 20 gpm, with specific capacities less than 1 gpm per ft of drawdown.

Water from wells in the structurally high areas typically ranges from 0 to 10 mg/l in hydrogen sulfide content, while water from wells located downdip from the structural highs generally contains concentrations ranging from 10 to more than 50 mg/l of hydrogen sulfide.

### INDIANA

#### Water budget of the upper Wabash River basin

A water-budget study indicated that of an average annual precipitation of 35 inches, only 10 inches of runoff occurs. Hydrograph analysis indicated that 34 percent of the runoff occurred as outflow from ground-water storage. The chemical quality of both surface and ground water is satisfactory for most purposes, although it is very hard (greater than 300 mg/l). Transmissivity of the sediments of Quaternary age is as much as 350,000 gpd per ft. Studies of the water resources of the basin are being conducted by C. H. Tate, R. E. Davis, L. E. Johnson and R. A. Pettijohn.

#### Ground water in small Ohio River tributary valleys

The most productive aquifer in the basin drained by the minor tributaries to the Ohio River along southern Indiana is the sand and gravel deposits in the deep channel of the Ohio River valley. This aquifer underlies about 8 percent of the basin and yields up to 3,000 gpm to wells. R. A. Pettijohn and J. P. Reussow report that the potential of the alluvial valley aquifer is of

such magnitude that it may be able to supply water for use in upland areas if fully developed. Full development would encompass maximum induced recharge of the Ohio River water to the aquifer.

The principal sources of ground water in the upland areas are the sandstone and limestone which underlie most of the basin. Some of these rocks yield up to 30 gpm on a sustained basis, but the average is about 5 gpm.

#### Ground water in the Whitewater River basin

Studies by R. J. Wolf indicate that the principal aquifer of the Whitewater River basin is the sand and gravel valley-train deposits. Thickness of this aquifer ranges from about 25 to 200 feet, and transmissivity ranges from 50,000 to 400,000 gpd per ft. Confining clay layers generally are not present, and recharge by induced stream infiltration is possible over most of the aquifer. The manageable ground-water resources of the basin amount to about 6.5 inches of the 39 inches of annual normal precipitation. This basin-wide yield has been subdivided into individual subbasin yields ranging from 245,000 to 330,000 gpd per sq mi.

### IOWA

#### Mississippian aquifer in southeastern Iowa

Investigation of the water resources in southeastern Iowa by R. W. Coble revealed that the Mississippian aquifer is separated into two systems by the Warsaw Limestone. Where the lower part of the aquifer is not covered by the Warsaw Limestone the dissolved-solids content of the ground water is usually less than 500 mg/l and yields to individual wells of more than 20 gpm are common. Where the Warsaw Limestone is present, the dissolved-solids content in the lower part of the aquifer is almost always more than 500 mg/l (around 1,000 to 2,500 mg/l in many places) and yields are less than 20 gpm. The upper part of the aquifer yields water with less than 500 mg/l of dissolved solids at rates of 20 gpm or more where shales of Pennsylvanian age do not cover the aquifer. In these areas, drilling through the Warsaw Limestone or into the lower portion is to be discouraged because no appreciable additional amounts of water will be encountered, and the chances of obtaining water of poor quality are greatly increased.

The entire Mississippian aquifer is covered by shales of Pennsylvanian age in the southwestern portion of the area. Here yields from the Mississippian aquifer are meager, and the dissolved-solids content of the water from both parts of the aquifer is 2,500 mg/l or more.

## MISSOURI

### Ground water in the St. Louis metropolitan area

L. F. Emmett found that the unconsolidated sand and gravel deposits adjacent to the Mississippi, Missouri, and Meramec Rivers in Jefferson, St. Charles, and St. Louis Counties are capable of yielding large volumes of ground water to wells for industrial and municipal use. Yields from irrigation wells in excess of 2,000 gpm have been measured in both the Mississippi and Missouri River alluvium. The maximum reported yield from a well in the Meramec River alluvium was 500 gpm.

Calcium, magnesium, and bicarbonate ions predominate in water from the alluvial deposits. However, where deep wells have been drilled in the flood plain into consolidated rocks containing saline water ranging from 8,000 to 10,000 mg/l total dissolved solids under artesian pressure, water from wells in the overlying alluvium may have a chloride content of several hundred milligrams per liter.

### Water resources of northwestern Missouri

E. E. Gann reported that the principal sources of fresh water in northwestern Missouri are the Missouri River and its alluvial valley, the alluvium of tributary valleys, and buried glacial valleys. The natural flow of tributary streams is generally undependable as a water-supply source except in the downstream reaches of the Nodaway, Thompson, Grand, and Chariton Rivers. Bedrock aquifers usually yield saline water with a total dissolved-solids content ranging from 2,000 to 20,000 mg/l, but some wells yield adequate water for domestic supply with less than 1,000 mg/l total dissolved solids.

Public water-supply districts have increased rapidly in the area to provide fresh water to small towns and rural areas unfavorably located with respect to dependable fresh-water sources.

## KENTUCKY

### Distribution of Lower Pennsylvanian aquifers

Lower Pennsylvanian sandstone aquifers yield fresh water from depths as great as 1,000 feet in the south-central part of the Western Kentucky coal field. On the basis of studies of electrical resistivity and induction logs of the numerous oil test holes in the area, R. W. Davis, R. O. Plebuch, and H. M. Whitman (Kentucky Geological Survey) concluded that the fresh water aquifer sands were deposited in two environments.

One environment of deposition was in channels cut into the underlying Mississippian rocks of Chester age.

This phase of sand deposition is mainly in the eastern half of the project area (mainly in Muhlenberg County). The channels in the western half of the area (mainly in Hopkins County) commonly are filled with sand and shale or principally shale and may not yield water to wells. The orientation of the channels is in a northeast-southwest direction.

The other environment of deposition of the aquifer sands is interpreted as being part of a Pennsylvanian deltaic system. The locations of the streams that carried sediment to the deltas appear to have been inherited from older channels. In the southwest quarter of the study area, the deltaic sands are laterally continuous, except where separated by faults. The deltaic deposits change facies abruptly from sand to shale in a southwestwardly direction, which was the direction of sediment movement. In the interfluvial areas between channels, the sands lie on or slightly above the uppermost Mississippian rocks; but above the channels, the deltaic sands overlies older Pennsylvanian channel-filling sediments.

The Pennsylvanian aquifer sands are in an area where surface water and shallow ground-water sources are usually of poor quality; moreover, low transmissivity values of 814 and 3,004 gpd per ft obtained from two pumping tests indicate that large yields may not be obtainable from the deeper sands and that even moderate withdrawals, such as 100 gpm, may lower the pumping levels of wells to near the top of the aquifer in about 5 to 10 years.

### Movement of ground water in karst areas

From a contour map of the water table in eastern Warren County, Ky., T. W. Lambert found that the ground water moves westerly from the Barren County line toward Barren River at Bowling Green. The direction of flow is not controlled by the regional dip of the limestone but is at right angles to it. Most of the discharge is at a large spring, locally known as Graham Spring, along the master stream, the Barren River, a few miles downstream from Bowling Green. Most of the discharge from Graham Spring joins the Barren River below the Bowling Green gaging station; however, the surface drainage area was included with that of the gaging station. In a karst area contouring of the water table is a useful tool in establishing surface drainage areas contributing to streamflow.

### Effects of pumping from Ohio River valley alluvial aquifer

The decline in ground-water levels at several recently established industrial sites in the Ohio River valley alluvium was a cause for alarm recently. D. V. White-

sides and P. D. Ryder (r2497) found in December 1967 that the area between Carrollton and Ghent, Kentucky, was being overpumped at industrial sites, but water levels about one-fourth to one-half mile from existing well fields generally were normal and fluctuated seasonally. Total amount of ground water in storage in the area is estimated to be 10.5 billion gallons. Recharge from precipitation and subsurface flow from bedrock is estimated to average about 3 mgd for the entire 5-sq-mi area and is insignificant when compared to the average ground-water withdrawals of 10 to 15 mgd from four well fields within the area. After water is pumped from storage in the aquifer, the only source of replenishment in large quantities is induced infiltration from the Ohio River. Well fields generally are not designed to take full advantage of river infiltration, however. Existing wells generally are grouped too closely together causing excessive well interference. Wells should be near to, and parallel with, the river to derive full benefit from induced infiltration.

Present pumpage from the area represents only a fraction of the available ground-water potential. However, proper well-field design and ground-water production management are necessary to receive full advantage of the available supply.

### TENNESSEE

#### Water resources in limestone areas

Correlations of flow at 23 partial record stations with nearby gaging stations indicated that the average flows of streams in the Center Hill Lake area range from 0.95 to 2.5 cfs per sq mi; the 7-day, 2-year flows range from 0 to 0.44 cfs per sq mi. G. K. Moore found that average flows had no apparent relation to geographic or geologic setting, but streams with the 10 lowest 7-day, 2-year flows drain either the Central Basin or the Cumberland Plateau. Streams with the 6 highest 7-day, 2-year flows drain the Highland Rim. The much thicker soil cover on the Highland Rim contains a reservoir of water to sustain low flows, but apparently does not affect the rate of evapotranspiration. Thus, there is no effect on average flow of the streams.

Streamflow measurements along East Fork Stones River indicated several gaining and losing reaches, as identified by Moore and C. R. Burchett. The shape and size of the solution openings that carry the water in losing reaches are unknown, but the openings must be fairly large. At several points, at least 30 cfs of water travels downstream beneath the streambed.

Areas near streams that have unusually low flows per square mile of drainage area may be good locations for

wells. An unusually large number of wells in these areas yields more than 50 gpm, whereas the average well yield for the whole basin is 10 gpm.

Wells in the Highland Rim generally yield more and better quality water than wells in the Central Basin. A preliminary analysis by Burchett in Bedford County, which is almost entirely in the Central Basin, showed that the average well yield is 17 gpm. The average hardness of the water is 220 mg/l. In Coffee County, which is mostly in the Highland Rim, the average well yield is 43 gpm and the average water hardness is 74 mg/l.

#### Ground-water yields in the Great Smoky Mountains National Park

Final results of drilling 49 wells in the park in Tennessee and North Carolina, 27 of which were test pumped, showed that well yields range from less than 10 gpm to more than 125 gpm and that specific capacities may be as low as 0.04 or as high as 13.8 gpm per ft of drawdown. Yields of wells in this area of Precambrian metamorphic rocks are related to topographic locations, thickness of saturated weathered material over bedrock, and proximity to major fault zones; but the results were too variable for simple correlation of site factors with yield. In addition, the effect of topography on yield could not be adequately evaluated since 42 of the 49 wells were in valley areas. W. M. McMaster has divided ground-water favorability areas into three categories: (1) ridge locations (least favorable), in which 7 wells were drilled which yielded 1 to 8 gpm and had a median yield of 4 gpm; (2) minor valley locations (moderately favorable), in which 25 wells were drilled which yielded 1 to 20 gpm and had a median yield of 6 gpm; and (3) major valley areas (most favorable), in which 17 wells were drilled which yielded 12 to 135 gpm and had a median yield of 67 gpm.

#### Water from terrace deposits draining into the "500-foot" sand in the Memphis area

As a result of the decline of water level, springs in the Memphis area have ceased to flow, and it is suspected that in some places water from the shallow terrace deposits is draining into the principal aquifer (the "500-foot" sand). J. H. Criner cited the presently available evidence of the shallow aquifer drainage: (1) hardness of the very soft water from the "500-foot" sand is gradually increasing (water from terrace deposits contain about 200 mg/l of hardness); (2) water level in the only long-term observation well in the probably discontinuous terrace deposits has declined

about 22 feet in the past 20 years, although, no wells are known to obtain water from the terrace deposits; and (3) a grounding electrode at a Memphis-owned electric substation, buried below the water table in the terrace deposits many years ago, was recently retrieved from "dry" sand. Loss of a grounding medium for power substations and the deterioration in chemical quality of the local water supply are two of the foreseeable ill effects of the draining.

## ALABAMA

### Ground-water potential of flood-plain deposits

Two 16-inch diameter test wells were drilled to aid in determining the availability of water from the flood-plain aquifer along the Alabama River in Dallas County, Ala. According to J. G. Newton and W. L. Broadhurst the flood plain is an agricultural area that includes about half a million acres and extends 300 river miles from Montgomery to the head of the Mobile River. The flood-plain deposits generally are not more than 50 feet thick and are tapped by numerous small capacity domestic and stock wells. The test wells are 47 and 54 feet deep. During preliminary development, each well was pumped at about 600 gpm. Results of these tests indicated potential supplies of water suitable for irrigation and other uses, but more tests will be made to aid in future development and utilization of the flood-plain aquifer.

## MISSISSIPPI

### Deep aquifers in Washington County

A 2,125-foot test hole at the Greenville port and industrial area, southwest of Greenville in Washington County, Miss., helped R. E. Taylor to define the lateral extent of fresh water in two potentially important aquifers. The Sparta Sand, the principal source of fresh-water supplies in the southern part of the county, and the Meridian-upper Wilcox aquifer, relatively unused in this county, were sampled at depths of 890 and 1,994 feet, respectively. The dissolved-solid concentrations were 1,960 and 1,080 mg/l for the two aquifers. Consequently, fresh water in the port and industrial area is available only from the Mississippi River alluvium and the shallow, Cockfield Formation. As fresh water is available from the Sparta Sand and Meridian-upper Wilcox aquifer in Greenville and eastward, public and industrial water supplies for the Greenville area should be developed from these deeper aquifers in order to conserve the fresh water in the Cockfield Formation for use west of Greenville.

### Baton Rouge area aquifers recharged in southern Mississippi

Geohydrologic cross sections constructed for a water-resources study in southwestern Mississippi by Roy Newcome, Jr., indicated that all the Miocene fresh-water aquifers below a depth of 1,000 feet at Baton Rouge, La., are recharged in Wilkinson, Amite, and Pike Counties, Miss., and possibly in more easterly counties just north of the 31st parallel of latitude. Most of the recharge area has sandy material of the Citronelle Formation (Pliocene age) at the surface. This formation, which is highly dissected but has a thickness as great as 200 feet in places, is very permeable and serves as a conduit for recharge to the underlying Miocene beds. Regional water-level declines average 1 ft per yr in the Miocene aquifers. Aggregate pumpage in the Mississippi counties named above is little more than 5 mgd; therefore, it is likely that the 110-mgd withdrawal from the deep aquifers at Baton Rouge accounts for at least a part of the regional water-level decline.

## LOUISIANA

### Water resources of southeastern Louisiana

Eight significant artesian aquifers were mapped by D. J. Nyman and L. D. Fayard in the Tangipahoa and Tchefuncte River basins in southeastern Louisiana, north of Lake Pontchartrain. The shallow aquifer sustains the flow of streams in the area. Highest ground-water discharge rates are along the upper three-fourths of the Tangipahoa River and the upper half of the Tchefuncte. Yields in the upper stream reaches generally exceed 0.5 cfs per sq mi and may exceed 1.0 cfs per sq mi. The shallow aquifer consists of sand and gravel that ranges from 0 to 500 feet in thickness and represents terrace and flood-plain deposits of Holocene to Pleistocene age. Most domestic wells tap this aquifer.

The deep fresh-water aquifers are distributed through the upper 3,000 feet of coastal plain sediments. The thickness of sands in this interval averages about 1,200 feet. The aquifers dip to the south and become salty beneath Lake Pontchartrain. All aquifers support flowing wells at low altitudes. In the southern part of the basins aquifers below depths of 2,000 feet may have about 100 feet of head above land surface. Yields of flowing wells which are 10-inches in diameter or larger may exceed 3,000 gpm.

The quality of water from ground- and surface-water sources is generally excellent; both are low in dissolved solids and objectionable constituents. Water from the shallow aquifer generally has a low pH and less than 1.0 mg/l iron and 25 mg/l hardness. The deep aquifers yield sodium bicarbonate water that generally has less

than 400 mg/l dissolved solids. Locally, iron and hydrogen sulfide are present in objectionable quantities.

### ARKANSAS

#### Hydrology of Horseshoe Lake

A hydrologic investigation by A. G. Lamonds indicated that the stage of Horseshoe Lake, in eastern Arkansas, is affected by changes in the stage of the Mississippi River and by the ground-water table in the vicinity of the lake. Interpretation of preliminary evaporation data and water-level measurements made during August, September, and October 1969 indicated that the net seepage out of the lake may exceed 5,000 gpm during periods of low river stage.

### ROCKY MOUNTAIN REGION

The program of geohydrologic investigations within the 12-state Rocky Mountain region reflects the extreme diversity of the environment. Wide variations in the topography, climate, and geologic history of the region have resulted in equally wide variations in the occurrence, availability, and quality of water. An increasing demand for hydrologic data of all types requires the continuation of programs for the collection and interpretation of basic information regarding the water resources of the region.

The following examples of studies under way within the cooperative programs with State and local agencies reflect a wide range of activities. An evaluation of the saline-water resources of the Rio Grande basin and the Tularosa basin was recently completed. Methods of artificially recharging aquifers are under way in the high plains of West Texas and eastern New Mexico, in a typical small stream valley in central Kansas, and in a ground-water management district in eastern Colorado. Changes in composition of stream flow caused by return flow of water from irrigated lands were studied in the Smoky Hill drainage basin in western Kansas. Changes in the chemical quality of water with time were studied in a newly-constructed reservoir in Texas.

Research projects in the Rocky Mountain region cover a wide spectrum in the field of hydrology. During the current year, significant results were obtained in such areas as improved analytical methods in water chemistry, detecting changes in aquifer characteristics by borehole geophysical methods in artificial recharge wells, development of computer programs to facilitate the analyses of data from evaporation studies, evaporation suppression by floating covers of polyethylene foam, and diffusion of heat in turbulent flow fields.

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

### ARIZONA

#### Water resources of Tucson basin evaluated

A study of E. S. Davidson indicated that the natural average annual recharge to the extensive aquifer underlying the Tucson basin is currently about 100,000 acre-ft. About 51,000 acre-ft is from infiltration of streamflow in the major stream channels; 31,000 acre-ft is recharged along the mountain perimeter of the basin; and about 18,000 acre-ft is underflow into the basin. The current average annual outflow from the aquifer is about 187,000 acre-ft. The outflow comprises about 162,000 acre-ft of pumped withdrawal, most of which is consumed; about 15,000 acre-ft is lost by evapotranspiration; and about 10,000 acre-ft is underflow out of the basin. The average annual streamflow into the basin is about 68,000 acre-ft, but only 17,000 acre-ft of streamflow leaves the basin.

### COLORADO

#### Electric analog model study of the San Luis Valley

P. A. Emery used an electric analog model in the evaluation of the water resources of the valley and showed that 70,000 acre-ft per yr of ground water can be salvaged by implementing a plan proposed, by the U.S. Bureau of Reclamation, for the San Luis Valley, Colo. The plan was designed to salvage ground water that is now being consumed nonbeneficially by evapotranspiration. A network of wells would lower the water table below the root zone of phreatophytic plants such as greasewood, rabbitbrush, and saltgrass, thereby depriving these plants of water. The salvaged water would be conveyed to the Rio Grande, making it available for beneficial consumption by downstream users.

The State of Colorado envisions that the plan will make more water available to the Rio Grande, thus helping to meet the requirements for water deliveries across the State line in accordance with the Rio Grande Compact.

The electric analog model simulated the pumping of about 84,000 acre-ft of water annually from 129 wells for a 50-year period of project operation. The model showed water-level declines ranging from 1 to more than 100 feet. The declines outside the boundaries of the designated water-salvage area, however, were generally less than 10 feet. The model showed that 84 percent of the water pumped would be derived from salvaged evapotranspiration. The reduction of storage in the ground-water reservoir accounts for 14 percent of the pumped water, and the remaining 2 percent would be induced flow from the Rio Grande. The net gain of

flow in the Rio Grande, therefore, would be 98 percent of the pumped water.

#### **Chemical quality of water in the San Luis Valley**

R. K. Glanzman, J. M. Dumeyer, and J. M. Klein found that ground water in the San Luis Valley is generally of good chemical quality, but that in some parts of the valley concentrations of dissolved solids, nitrate, fluoride, and color exceed those concentrations generally recommended for public supplies. The highest concentrations of dissolved solids occur northeast of Alamosa, where water in the unconfined aquifer in nonirrigated areas contained 31,500 mg/l and the confined aquifer contained 2,480 mg/l dissolved solids. In general, the dissolved-solids concentration of ground water is less in the upper part of the confined aquifer than it is in the unconfined aquifer. Nitrate concentrations as much as 138 mg/l occur in water from the unconfined aquifer in the irrigated area northwest of Alamosa. In the northern half of the valley, water in the confined aquifer had fluoride concentrations of as much as 13 mg/l and color intensity of as much as 520 American Public Health Association (APHA) units.

#### **Availability of water for artificial recharge in the high plains of Colorado**

Surface water available for artificial recharge in the 1,400-sq-mi Plains Ground-Water Management District in Kit Carson County, Colo., averages less than 12,000 acre-ft annually. The average annual surface flow out of the District was estimated to be 12,000 acre-ft by C. T. Jenkins and W. E. Hofstra (r1280) from records of gaging stations on two streams and from stream geometry measurements at 13 sites. Because the flow is highly variable, several large impounding structures would be required to capture a major part of the streamflow for use in artificially recharging the Ogallala aquifer. However, the quantity of water that could be captured would be considerably less than 12,000 acre-ft per year if the impoundments were constructed up-gradient from the area of substantial ground-water use.

#### **Irrigation return flow to the South Platte River**

Measurements of streamflow at selected points on the South Platte River between Henderson, Colo., and the Colorado-Nebraska State line showed that most reaches of the stream were gaining water before, during, and after the irrigation season. The measurements were made in November 1966; March and November 1967; and March, August, and November 1968, by D. R. Minges under the direction of D. R. Albin. All reaches were gaining water except the reach downstream from Crook, Colo., where losses of as much as 2 cfs per mi were measured in November 1966 and in November

1968. The greatest gain, 10 cfs per mi, was measured in November 1968 in the reach between Goodrich and Weldona. The average gain between Henderson and the State line was 3.4 cfs per mi.

#### **Simulation study of the Arkansas River valley in Colorado**

According to E. A. Moulder and J. E. Moore a digital-computer model of the stream-aquifer system in the Arkansas River valley was developed by using results obtained from an electrical-analog model. The digital model then was used to make a preliminary evaluation of current water management practices. Two methods of managing water were analyzed. The first analysis showed how much water might be delivered by using only the surface-water supply. The second analysis showed how the supply could be improved by using ground water. The two analyses suggested strongly that greater utilization of the ground-water reservoir was possible and that much of the deficit that occurs late in the season during dry years could be overcome.

The digital model is now being calibrated by comparing ditch diversions, precipitation records, and pumpage data with streamflow records. When calibration of the digital model is completed, it will be used to develop management and administrative optimization programs.

### **KANSAS**

#### **Large well yields available from Missouri River valley alluvium**

A study by C. K. Bayne (State Geological Survey of Kansas) revealed that large quantities of water (up to 2,000 gpm) are available from properly constructed wells in alluvial deposits in the Missouri River valley in Doniphan County, Kans. In tributary valleys, yields generally less than 10 gpm are available. Yields of wells in glacial drift in the upland areas of the county are generally less than 10 gpm; however, yields up to 100 gpm can be obtained from buried preglacial channels in the drift area.

Water throughout the county is a calcium bicarbonate type, generally containing less than 500 mg/l dissolved solids. However, concentrations of nitrate in excess of recommended limits occur in many places in the county and water from the Missouri River valley contains concentrations of iron ranging from 5 to 25 mg/l.

#### **Storage coefficient of the Ogallala Formation**

E. D. Jenkins and T. J. McClain (State Geological Survey of Kansas) found that 250 wells tapping the Ogallala Formation within a 340-sq-mi area of Sherman County, Kans., pumped 180,000 acre-ft of water during the 4-year period 1966-70. Water levels declined from 1 to 14 feet, and averaged 5 feet. The

volume of dewatered sediments was about 1,088,000 acre-ft. If one neglects recharge, and as the volume of water pumped amounted to 17 percent of the volume of dewatered sediments, the apparent storage coefficient is about 0.17.

#### **Infiltration of irrigation water alters ground-water quality**

Water-quality studies in the Cedar Bluff Irrigation District showed that during the first five years of irrigation, water applied in excess of crop requirements augmented and partially displaced ground water initially in storage beneath the irrigated area. Migration of the chemically altered excess irrigation water progressively changed the chemical composition of well water downgradient and altered the composition of return flow to the Smokey Hill River. Ground-water effluent comprised progressively larger proportions of low streamflow downstream from the irrigation district. R. B. Leonard, project chief, noted that if present trends continue eventually the aquifer will be flushed, and the chemical quality of the irrigation water and return flow will be more nearly the same.

#### **Appraisal of ground-water supplies in Atchison County**

Ground-water studies by J. R. Ward (State Geological Survey of Kansas) in Atchison County, Kans., showed that a major stream valley system filled by deposits of Pleistocene (Illinoian(?)) to Holocene age extends from west to east across the county. The buried-stream system is at least as old as early Nebraskan. Yields of wells in the Pleistocene deposits are generally greatest near buried valleys. Yields of up to 250 gpm are obtained from valley fills of limestone and chert gravels resting directly on bedrock of Late Pennsylvanian age. In areas away from buried valleys, smaller but adequate domestic and stock supplies exist in unconsolidated deposits which have 20 to 30 feet of saturation. Supplies of water from the alluvium are generally small to moderate, except in the Missouri River valley where wells may yield as much as 2,000 gpm. Bedrock yields are generally small.

Water-table conditions generally exist throughout the county, but in four localities water is under artesian pressure and flowing wells may be constructed. The largest of these areas is south of Muscotah in the Delaware River valley.

The water throughout the county is generally a very hard calcium bicarbonate type. Concentrations of nitrate of as much as 359 mg/l cause local problems.

## **MONTANA**

### **Water-level declines mapped in southeastern Montana**

Water-level declines were mapped by D. L. Coffin in the Fox Hills-Hell Creek aquifer along the Cedar Creek anticline in southeastern Montana. The maximum decline of 133 feet was caused by withdrawals of water for industrial use, domestic supply, and livestock during the period 1962 to October 1969.

### **Water resources of the Northern Cheyenne Indian Reservation and adjacent area**

According to project chief, W. B. Hopkins, surface-water supplies for the reservation are available from the Tongue River and from Rosebud Creek. The average discharge of Tongue River at the Montana-Wyoming State line is about 340,000 acre-ft per year; the discharge of Rosebud Creek was estimated to be between 15,000 and 20,000 acre-ft in 1968.

Ground water is obtained from alluvium, the Tongue River Member of the Fort Union Formation, the Hell Creek Formation, and the "clinker" beds (baked or fused rock altered by burning of underlying coal). Public supply wells yield from 50 to 250 gpm from alluvium. Most other wells and springs yield less than 15 gpm. Springs and shallow wells yield hard, calcium bicarbonate water, but wells over 100 feet deep yield soft, sodium bicarbonate-sulfate water. The concentration of dissolved solids is lower in surface water than in ground water but more variable.

### **Gravity study of the southern Flathead Valley**

A gravity study of the southern part of the Flathead Valley has disclosed the configuration of the bedrock surface. The valley is a north-south trending grabenlike structure with valley-fill deposits that are thickest along the east side near the front of the Mission Range. The gravity study is part of an investigation of the water resources of the area being conducted by W. B. Hopkins and R. G. McMurtrey. The area of thickest valley fill may be capable of producing large ground-water supplies.

### **Discharge area for Fox Hills-basal Hell Creek aquifer determined**

A study of the geology and water resources of a part of southeast Montana by W. R. Miller indicated that ground water is discharged from the Fox Hills-basal Hell Creek aquifer in the central Powder River Valley where the Hell Creek Formation is exposed. This discharge, which creates a trough of depression in the water table along the Powder River, is the result of upward leakage through the Hell Creek Formation and the uncontrolled flow of artesian wells.



Chemical analyses of water from the Fox Hills-basal Hell Creek aquifer show that the water is of the sodium bicarbonate type. The dissolved-solids concentration in the water varies from about 300 mg/l near the outcrop to as much as 1,000 mg/l about 35 to 40 miles downdip.

#### NORTH DAKOTA

##### **Melt-water channel aquifers in Mercer and Oliver Counties**

Test drilling in Mercer and Oliver Counties, N. Dak., defined several glacial melt-water channels that contain 200 to 300 feet of saturated sand and gravel according to M. G. Croft. The most important aquifers underlie Goodman Creek, the Knife River, and a valley commonly called the Beulah trench. Properly constructed wells in these deposits should yield about 500 gpm of water that is generally suitable for irrigation.

The coarse deposits in the Beulah trench form a highly permeable conduit connecting Lake Sakakawea and the Knife River valley. The hydraulic gradient in the trench indicates that water from the lake (elev. 1,840 feet) percolates southward in the subsurface to the Knife River valley (elev. 1,750 feet).

##### **New aquifers found in Nelson and Walsh Counties**

Subsurface exploration in northeastern Walsh County by J. S. Downey during 1969 disclosed the presence of a significant thickness of Jurassic(?) siltstone that contains water with more than 20,000 mg/l dissolved solids. Water in a small glacial aquifer overlying the siltstone has been contaminated by the highly mineralized water from the bedrock unit.

A sand and gravel aquifer in Nelson County, which is buried beneath as much as 100 feet of till, extends from near the city of McVille northwestward beneath east Stump Lake into Ramsey County. Water levels in this aquifer near east Stump Lake are above the normal water level of the lake, indicating groundwater movement from the aquifer to the lake. Water in the aquifer contains about 900 mg/l dissolved solids.

##### **Ground water in Cavalier and Pembina Counties**

According to R. D. Hutchinson test drilling in western Cavalier County, N. Dak., in 1969 located an extensive aquifer system in the glacial deposits that will yield as much as 100 gpm of relatively good quality water.

The 80-sq-mi Pembina Delta deposit, which is as much as 150 feet thick, was once considered to be a

major aquifer. However, test drilling shows that generally only a few feet of saturation is present.

Only about 5 percent of the ground water in common use in Cavalier and Pembina Counties contains dissolved solids concentrations of less than 1,000 mg/l. Some wells yield water with dissolved solids of as much as 54,000 mg/l.

##### **Buried channel discovered in McLean County**

R. L. Klausing reported that test drilling revealed that a buried interglacial valley more than 400 feet deep traverses western McLean County. In the northwestern part of the buried valley, saturated sand and gravel deposits are generally less than 100 feet thick, but in the southeastern part of the valley, the saturated deposits may be as much as 150 feet thick. Comparison of water-level data and stage-height records indicates that in the southeastern part of the valley the aquifer is in hydraulic continuity with Lake Sakakawea.

The aquifer contains a sodium-bicarbonate type water with 1,000 to 1,430 mg/l dissolved solids.

##### **Buried-valley aquifers in Benson and Pierce Counties**

A study by P. G. Randich indicated that a buried-valley aquifer in southwestern Pierce County contains a till constriction that causes water levels on the upgradient side to be about 40 feet higher than those on the downgradient side. The average aquifer thickness is about 150 feet, except in the area of the constriction where it thins to less than 10 feet. The constriction coincides with a glacial terminal moraine on the surface.

Another buried-valley aquifer was found underlying the surficial outwash deposits near Warwick in eastern Benson County. The aquifer apparently underlies most of the Devils Lake chain and extends northwest from Minnewaukan. The buried-valley aquifers are known to yield about 1,000 gpm to wells.

##### **Position of the Lemmon syncline, Hettinger and Stark Counties**

Henry Trapp, Jr., in studying structure contours on the contact between the Sentinel Butte and Tongue River Members of the Fort Union Formation found that the axis of the Lemmon syncline trends northward through southeastern Hettinger County to the Cannonball River valley about a mile east of Mott. The axis then follows the Cannonball River valley to a point halfway between Mott and Regent, then north and northeast to the Heart River Valley about 8 miles southeast of Gladstone, and then northwest along the valleys of the Heart and Green Rivers. Branches of the main syncline trend southwest of Dickinson along

the valleys of the Heart River and Ash Creek (Little Badlands). There are also indications of structural lows in the valley of the Cannonball River east of Burt and in the vicinity of New England. It appears that the position of streams in this area is, in part, structurally controlled.

### OKLAHOMA

#### Appraisal of ground-water supplies in south-central Oklahoma

D. L. Hart, Jr., reported that a hydrologic reconnaissance of the Ardmore and Sherman  $1^{\circ} \times 2^{\circ}$  quadrangles (an area of more than 9,000 sq mi in south-central Oklahoma) revealed several areas with considerable potential for development of ground-water supplies. Some wells completed in the limestone of the Arbuckle Group in the central part of the area yield more than 2,500 gpm, and wells yielding 500 gpm are common in this aquifer.

Other aquifers having significant potential for well development are the Vamoosa Formation and the Oscar Sandstone of Bunn (1930),<sup>46</sup> both of Pennsylvanian age, which yield as much as 200 gpm, the Rush Springs Sandstone of Permian age, which yields up to 150 gpm, the Paluxy Sand of Lower Cretaceous age, which yields as much as 300 gpm, and some small areas of alluvial and terrace deposits of Quaternary age, which yield up to 600 gpm. The water from these aquifers is generally of fair to good quality.

Large areas in the western, northern, and eastern parts of the study area are underlain by shale, siltstone, and tightly cemented sandstone which yield only meager quantities of ground water of fair to poor quality.

Surface-water reservoirs constitute a major source of water supply in the area. Most of the streams are dry during part of the year, and the quality of the surface water during periods of low flow is often poor. However, where reservoir storage is provided, dilution of the poor quality water by storm runoff results in adequate supplies of water suitable for most uses.

#### Appraisal of ground-water supplies in southeastern Oklahoma

M. V. Marcher and D. L. Bergman on completion of the preliminary phases of a hydrologic reconnaissance of the McAlester and Texarkana  $1^{\circ} \times 2^{\circ}$  quadrangles (an area of about 8,200 sq mi in southeastern Oklahoma) found that several geologic units have potential for development of ground-water supplies. Yields of several hundred gallons per minute may be

expected from properly constructed wells in alluvium along the Red River. Water from the alluvium is commonly hard and reported to be saline in local areas.

In the Coastal Plain province, which includes the southern one-fourth of the study area, the Paluxy (Antlers) Sand is the only aquifer of significance. At present, this aquifer is relatively undeveloped although it is capable of yielding as much as 300 gpm and possibly more. South of the outcrop area, water in the Paluxy Sand is under artesian pressure, and some wells flow from a few gallons to several tens of gallons per minute. The water is commonly hard and locally contains excessive amounts of iron. Water from deeper parts of the formation is saline in some areas. Other formations underlying the Coastal Plain province generally yield only enough water for domestic use, and much of the water is of poor quality.

The northern three-fourths of the study area is underlain by highly folded and faulted siliceous shales, well-cemented sandstones, and chert or novaculite. The shales and sandstones generally yield only limited amounts of water of variable quality. In the Potato Hills area, which straddles the line between Latimer and Pushmataha Counties, the Bigfork Chert may be a source of moderate water supplies. Another possible source of moderate water supplies is the Arkansas Novaculite in the so-called "core" of the Ouachita Mountains in central McCurtain County. Both the Potato Hills and "core" areas are rather remote, and no attempts have been made to develop supplies other than for domestic use.

### SOUTH DAKOTA

#### Glacial aquifer in Marshall County

A systematic program of test drilling and well inventory by N. C. Koch and W. L. Bradford indicated that a glacial artesian aquifer that ranges in thickness from about 20 to 70 feet underlies an area of about 22 sq mi in the northeastern part of Marshall County. The bottom of the aquifer is generally within 150 feet of the land surface and the depth to water in three observation wells ranges from 12 to 70 feet below land surface. Specific conductance of the water ranges from 1,600  $\mu$ mhos at the western edge of the aquifer to 870  $\mu$ mhos at the Marshall-Roberts County line. The aquifer is a primary source of water for domestic and farm use in the area.

#### Aquifer delineated in Faulk County

D. G. Jorgensen conducted ground-water studies in Faulk County and outlined the extent of a virtually unused sand and gravel aquifer composed of glacial outwash deposits. The aquifer, which is more

<sup>46</sup> Bunn, J. R., 1930, Oil and gas in Oklahoma, Jefferson County: Oklahoma Geol. Survey Bull. 40, v. 2, p. 341-381.

than 50 feet thick, in many places, is generally overlain by 100 to 250 feet of till. In Faulk County, it underlies an area of about 50 sq mi and extends for approximately 30 miles from near Miranda to Faulkton and northward into Edmunds County. The only use of water from the aquifer at present is for municipal supply at Faulkton and for livestock supply near Miranda. The water is a sodium sulfate type and high in dissolved solids.

#### **Natural ground-water discharge into Choteau Creek**

A study by Jack Kume established that the potentiometric surface of the Choteau aquifer ranges in altitude from 1,500 feet in northeastern Douglas County to 1,200 feet in southeastern Charles Mix County. The gradient of the potentiometric surface and the direction of ground-water flow in Choteau aquifer are southward. Natural ground-water discharge from the artesian Choteau aquifer occurs in the channel of Choteau Creek in a reach that extends from the mouth to about 18 miles upstream. The channel intersects the potentiometric surface of the Choteau aquifer at an altitude of 1,375 feet above mean sea level. Stream-discharge measurements made from 1966 to 1969 showed that the base flow, which was continuous during this period, ranged from 0.25 cfs to 2.50 cfs.

### **TEXAS**

#### **Quality-of-water study of the Angelina River and Sam Rayburn Reservoir**

Studies of the Angelina River and Sam Rayburn Reservoir, Tex., by Jack Rawson and M. W. Lansford indicated that waste effluents have caused some local deterioration of the quality of the river downstream from Lufkin, Tex. However, the volume of flow in the river has been adequate to prevent serious deterioration of the quality of water in Sam Rayburn Reservoir. The volume-weighted dissolved-solids content of water in the reservoir ranged from about 105 to 145 mg/l during 13 surveys from April 1965 to February 1969.

During 10 reservoir surveys the dissolved-oxygen content of water at deep sites near Sam Rayburn Dam averaged more than 5 mg/l. At a site about 41.5 river miles upstream from the dam, the oxygen content averaged 4.2 mg/l. Data from tributary arms of the reservoir indicate that a large part of the oxygen depletion was caused by the decomposition of naturally occurring organic debris.

The concentrations of dissolved iron and manganese in Sam Rayburn Reservoir varied seasonally and usually were much lower during periods of winter circulation than during periods of summer stagnation. During

each of three reservoir surveys made in February, water near Sam Rayburn Dam contained less than 0.40 mg/l iron and 0.25 mg/l manganese. However, on October 6, 1965, the iron content of water near the dam ranged from less than 1 mg/l at depths less than 30 feet below the surface to more than 8 mg/l at depths greater than 30 feet. Similarly, on September 9, 1966, the manganese content of the water ranged from less than 0.5 mg/l at depths of less than 10 feet to more than 5 mg/l at depths greater than 50 feet.

### **UTAH**

#### **Depth to the base of the Quaternary deposits in the Jordan Valley**

The depth to the base of the Quaternary deposits in the Jordan Valley was determined from drillers' logs of water wells and other geological and geophysical data according to Ted Arnow, Richard Van Horn, and Reed LaPray (p. D257-D261). The pre-Quaternary surface of the valley generally was similar to the present land surface but had considerably more relief. A contour map of the base of the Quaternary deposits was prepared to provide a general guide for water-well drilling and to provide an indication of the maximum depth to formations underlying the unconsolidated Quaternary deposits.

#### **Alluvial aquifer in eastern Cache Valley**

A study by L. J. Bjorklund and L. J. McGreevey revealed an extensive aquifer containing water under both water-table and artesian conditions in an area of approximately 120 sq mi on the east side of Cache Valley in the vicinities of Smithfield, Logan, Hydrum, and Wellsville, Utah. Aquifer tests indicated transmissivities of 21,000, 214,000, and 330,000 cu ft per ft per day. The aquifer consists of alluvial sand and gravel, composed mostly of limestone. The extremely high transmissivities suggest partial solution of some of the alluvial particles. Hydrographs for wells in the area also suggest that transmissivity of the aquifer is high.

#### **Ground-water resources of the east shore area of Great Salt Lake**

A study made by E. L. Bolke and K. M. Waddell of recent well drilling in previously undeveloped parts of the east shore area of Great Salt Lake showed that usable ground-water supplies exist at depths as great as 1,200 feet. Preliminary analysis of these data suggests that some of the aquifers in the east shore area are both more permeable and more areally extensive than was previously believed.

Chemical-quality monitoring of wells since 1962 indicates that only minor changes in quality have oc-

curred, although water levels have declined substantially in some parts of the area.

#### **Ground-water resources of the Virgin River basin**

R. M. Cordova, G. W. Sandberg, and Wilson McConkie found that alluvial fans and channel-fill deposits are the most productive aquifers in the basin, but that older consolidated rocks yield some water to wells locally. They determined that ground-water recharge and discharge in the Virgin River basin are in equilibrium, and that each averages 80,000 to 100,000 acre-ft per year.

#### **Ground-water recharge in Jordan Valley**

A study by A. G. Hely, R. W. Mower, and C. A. Horr showed that of the precipitation on the Wasatch Range in Salt Lake County, subsurface outflow amounts to about two-thirds of the normal surface runoff. For individual basins that are monitored by surface-water gages, the subsurface outflow ranges from about 15 to about 150 percent of the surface runoff. The subsurface outflow is a major component of the recharge to the principal aquifer in Jordan Valley.

#### **Chemical quality of Green River modified by reservoir**

R. J. Madison ascertained from continuous records of chemical quality beginning in 1956 that the concentration of dissolved solids in the outflow from Flaming Gorge Reservoir increased 100 to 150 mg/l in the 6-year period since closure of Flaming Gorge Dam. This increase was about 35 percent more than would have been expected without the reservoir. It was estimated that approximately 1,200,000 tons of solutes were added to the system by leaching during the 1963-68 period, and that the leaching accounted for most of the increased concentration downstream. The initial reconnaissance indicated that the rate of leaching did not significantly decrease through the first 6 years since closure. During three separate sampling periods, considerable stratification of dissolved solids was observed in the reservoir. Although the average dissolved-solids concentration of the Green River below the reservoir increased, the seasonal fluctuation in concentration and chemical character is considerably less than it was before closure of Flaming Gorge Dam.

#### **Water supply at Canyonlands National Park**

C. T. Sumsion found out that water for the Island-In-The-Sky area of Canyonlands National Park in southeastern Utah could be obtained from two wells in adjacent Taylor Canyon. The combined yield of the two wells is 130 gpm—enough to meet anticipated needs. The water is mineralized and will require treatment for general use. The aquifer is the White Rim

Sandstone Member of the Cutler Formation of Permian age. The White Rim Member, where present south and east of Island-In-The-Sky, does not bear water.

### **PACIFIC COAST REGION**

The Pacific coast region encompasses an area of diverse hydrologic and geologic terrane, extending from the bleak Arctic to the arid desert to the lush islands of the Pacific. The variations and contrasts in its hydrologic character are reflected in the diversity of its hydrologic problems, which are rendered more complex by competing uses for water and imbalances in supply and demand both in time and in place.

Hydrologic problems in the region are many. They include sea-water intrusion into coastal aquifers; pollution in all its forms; natural disasters such as floods, droughts, and earthquakes; the effects of volcanic activity upon ground-water reservoirs; wasteful consumption of water by phreatophytes; permafrost in some areas and aridity in others; the unabated growth of population centers in water-deficient areas; ground-water withdrawals in excess of replenishment; land subsidence; and the effects of urban development upon stream flow.

To provide solutions or to ameliorate these problems, the U.S. Geological Survey is making water-resources studies in each of the seven States of the Pacific coast region. Some studies are designed to meet an immediate need, such as locating new water supplies in a basin, forecasting flood flows of rivers, or determining the path of travel of contaminants. Other studies in the region are more of a research nature, such as investigating the dynamics of glaciers or the ecology of lakes. As in the other regions, the element common to all studies is the objective of preventing deterioration of the hydrologic aspect of our environment.

Perhaps northern Alaska, almost untouched in terms of hydrologic study, is worthy of special mention. Little work has been done in this area in the past because of lack of an immediate need for information. Concomitant with the recent interest in the area shown by the petroleum industry, however, is the very pressing need for information on the quality, availability, and year-round dependability of water supplies on the North Slope, and methods of development. Several reconnaissance trips were made into that area during the year to assess the problems and to form a base on which to build the more extensive and intensive studies that are in the design stage.

As an integral part of the Geological Survey's national activities, basic data continue to be collected in the Pacific coast region on streamflow, ground-water levels, chemical quality, water temperature, and

sediment transport. The data are useful to managers and planners, and provide a factual base for present and future studies.

Summarized in the following paragraphs are some of the more significant contributions to the hydrologic knowledge of the region made during the year by projects completed or in progress.

## HAWAII

### Water table mapped in Kailua area

A study of part of the Kailua area on the island of Oahu showed that the area is underlain by coralline sand to an undetermined depth below sea level. According to C. J. Huxel, Jr., and Santos Valenciano, the water table mounds upward beneath the area, normally to altitudes of from 1 to 3 feet above sea level. Occasionally flooding occurs when the water table rises above the ground surface during periods of heavy rain and runoff. Recharge to the ground-water body is provided by infiltration of precipitation and possibly by lateral movement from an adjacent swamp.

### Basal ground water promising in southeast Maui

K. J. Takasaki and George Yamanaga found that fresh basal ground water in Kipahulu and Kaupo Valleys may be the most promising source of large dependable water supplies in southeast Maui. However, basal ground water near the shore in the drier western part of the area is not likely to be of adequate quality to warrant development. Still unknown is the occurrence and availability of ground water beneath the higher slopes inland from the coast, and in the rift zone of Haleakala Volcano; test drilling will be required to explore supplies in these areas.

## MIDWAY ISLANDS

### Water supply of Sand Island

D. A. Davis reported that rainfall maintains a thin lens of fresh to brackish water in the generally permeable sand of Sand Island, a 1,000-acre island in the Midway Islands group. Precipitation averages about 44 inches per year. Under natural conditions the chloride content of the ground water ranges from about 100 mg/l in the center of the island to about 5,000 mg/l near the shore where mixing with sea water is greatest. Pumping at several wells dug near the center of the island causes an increase in the salinity of the ground water, and pumping of these wells at intermittent rates of 40 to 50 gpm causes a several-fold increase in chloride content within periods of several days to several weeks thereafter.

## AMERICAN SAMOA

### Fresh water plentiful on island of Tutuila

Well drilling and pumping tests on the island of Tutuila showed that the thin lava flows of Holocene age which underlie part of the Tafuna-Leone plain are highly permeable and contain large quantities of fresh water. According to K. J. Takasaki and R. H. Dale, the tests also showed that lava flows under the plain apparently become progressively thicker and less permeable toward the older volcanic mountains in the central part of the island. The aquifer in nearshore areas is subject to sea-water intrusion.

The most productive wells outside the Tafuna-Leone plain have been drilled in the thick alluvial and talus fill of Pago Valley. The island's volcanic rocks, with the exception of the lava flows on the plain, generally have low permeability, although some highly weathered volcanic rock is sufficiently permeable to yield small quantities of water to a few wells.

## ALASKA

### New location for municipal wells in Anchorage area

The 5-year cooperative geohydrologic study of the Greater Anchorage Area Borough continued into its fourth year. Regional drawdown and change maps on the potentiometric surface of the artesian aquifer underlying the Anchorage area indicated that future municipal wells should probably be drilled in the natural recharge zone along the west flank of the Chugach Mountains, about 3 to 4 miles east of the city's present well field. The study also showed that artificial recharge might significantly increase the yields of existing municipal wells drilled to the artesian aquifer. According to W. W. Barnwell and J. B. Weeks, aquifer tests at one site along Ship Creek suggested that artificial recharge of about 5 mgd may be possible from surface spreading.

R. S. George and L. L. Dearborn prepared a preliminary areal water-table map that suggests that most water levels of the shallow, lowland lakes in the Anchorage area are related to the water table.

### New sources of water for Kenai

Continuing studies in the Kenai area are defining the availability of ground water for industrial and municipal supplies in greater detail. G. S. Anderson and S. H. Jones reported that initial test drilling east of the city of Kenai located a buried outwash channel that may yield more than 1,000 gpm to properly developed wells. Artesian flow of 600 gpm was obtained from each of two test wells, and the water was of good

quality, having an iron content of less than 1 mg/l. This newly located source promises to be more adequate than the city's present source of ground water. Yields from present wells are less than 100 gpm and the iron content of the water ranges from 1 to 15 mg/l.

The water requirements of the area could be satisfied by diversions from the Kenai River. The water would require treatment to remove glacial flour, but study of the lower Kenai estuary during low flow and maximum tidal period shows that water intakes could be placed 12 river miles above the mouth without danger of significant salt-water contamination.

#### **Continued study of Mendenhall Valley**

Ground-water levels in the Mendenhall Valley of the Greater Juneau Borough are more closely related to precipitation than to the flow of the Mendenhall River. Evidence cited for this conclusion by J. A. McConaghy includes, for example, a 5-foot rise in water level in an observation well following a 10-inch rainfall (about 2.7 inches greater than normal). The event occurred in September when streamflow decreased slightly from the preceding month. In another phase of the study, preliminary computations comparing the Mendenhall River to Montana Creek, a nearby glacial stream, indicated that about 50 percent of the annual discharge of the river is composed of glacial melt water, and the average annual gain from glacial storage may be as much as 450,000 acre-ft per yr.

#### **Water supplies adequate at National Park Service areas**

After performing an aquifer test, Chester Zenone reported that a new well 20 feet deep at Teklanika Campground in Mount McKinley National Park will yield 50 to 75 gpm. Future water needs could probably be satisfied by other shallow wells in the same general area. Shallow subsurface investigations made with jetting equipment were also conducted along a small unnamed stream in the Wonder Lake area, near the northwest corner of the park. The tests indicated that ground water of good quality is probably available.

As part of a continuing investigation in Katmai National Monument, Zenone and E. M. Chase found that adequate ground water of good quality is available in the Monument Headquarters area. Using portable jetting equipment, they completed several shallow test wells in alluvium. Additional exploratory jetting along the shore of Naknek Lake and also near a trapper's cabin in the Bay of Islands area indicated that small supplies of ground water would probably be obtained by properly drilled production wells.

### **WASHINGTON**

#### **Digital model for Walla Walla River basin**

Data have been collected with which to develop a digital model of the Walla Walla River basin in southeast Washington and northeast Oregon. A model having two layers was originally planned to simulate the hydraulic interaction of a gravel aquifer in contact with the basalt aquifer which underlies the entire basin. However, data collected over a 12-month period by R. D. MacNish indicated that the two units are hydraulically separated by materials of low permeability, and that the two aquifers can be successfully modeled separately. A series of measurements made in both aquifers in January 1969, and again in January 1970, showed that little or no change had occurred in the position of the water table in the gravel aquifer, whereas the potentiometric surface in the basalt aquifer had dropped as much as 11 feet in certain areas. In the area of greatest depression of the potentiometric surface, heavy pumping had occurred, but the reason for such a depression is more complex, for there has been equally heavy pumping in other areas where the piezometric surface has changed little from the previous year.

### **OREGON**

#### **Alluvial deposits most productive in Eugene area**

The Eugene-Springfield area has large quantities of ground water available, but the varied character and extent of the geologic units cause great differences in availability and chemical quality of the ground water. F. J. Frank found that water from some sedimentary rocks is of poor chemical quality, and that volcanic rocks of the upland parts of the area are poor aquifers. Most productive of the aquifers are the sand and gravel deposits of the McKenzie and Willamette Rivers which commonly yield moderate to large quantities of good-quality water from depths of only a few feet below the land surface.

#### **Ground-water quality and quantity erratic in Harney Valley**

The quantity and quality of ground water vary erratically from place to place in Harney Valley. According to A. R. Leonard, some wells produce several hundred gallons of water per minute whereas other wells drilled to lower levels, even to depths of 500 to 600 feet, produce only a few gallons per minute. Near Burns and around the margins of the valley, water is generally of good quality for irrigation. At scattered locations throughout the valley, however, the ground water commonly contains a high percent sodium despite its low, total-mineral content. In several places the

ground water also contains boron in excess of acceptable limits for irrigation.

### CALIFORNIA

#### Temperature data of California streams to be published

A new series of reports will present water temperature data at selected sites along California streams. The first report, compiled by J. C. Blodgett, contains data current through the 1968 water year for 120 sites in the north coastal subregion. Included are continuous records for 50 sites in operation since 1951 and periodic data for 118 sites with varying periods of operation—as long as 18 years. The data are summarized by years, months, and periods of record, and are stored on tape for future analytical studies. An analysis of the water-temperature records indicates that departures from probable values are not greater than  $\pm 0.75^{\circ}\text{C}$  for thermograph data and  $\pm 0.56^{\circ}\text{C}$  for periodic data.

#### Channel capacity of parts of Tuolumne and San Joaquin Rivers studied

The adequacy of a 52-mile reach of the Tuolumne River to carry flood flows was described in a channel-capacity report by J. C. Blodgett (r2027). Maps, photographs, profiles, cross-sections, stage-discharge relations, and a backwater probability curve indicate the extent of flooding that has occurred and that which may be expected to occur in the future. The report will be useful for defining the primary floodway and for minimizing vulnerability to flood damage.

Water-surface profiles for 37.3 miles of the San Joaquin River downstream from the Friant Dam were delineated by K. W. Lee (r0787) prior to two record releases of water. Maximum releases of 8,230 cfs occurred on May 23, 1967 and 12,400 cfs on June 6, 1969. Both flood profiles indicated that inundation of some low-lying areas would occur, which was subsequently confirmed by the use of aerial photographs following the first release and by field observations following both releases.

#### Changes in ground-water regimen in Gilroy-Hollister basin

Continued study of the Hollister and San Juan sub-basins by Chabot Kilburn has disclosed changes in ground-water levels and directions of movement between the years 1913 and 1968. In 1913 the ground water flowed toward the north in the Hollister Valley, whereas in the San Juan Valley the flow pattern was westward to points of discharge in the San Benito and Pajaro Rivers. Artesian conditions prevailed in much of the area. Ground-water withdrawals over the 55-year interval have caused water-level declines of about 180 feet in Hollister Valley and about 100 feet in San

Juan Valley. Large cones of depression now occur in these and in one adjoining subbasin, and the direction of ground-water movement has been appreciably affected, even to the point of being reversed in some parts of the basin. Little or no ground water now leaves the valleys either by surface outflow or by underflow.

#### Ground water studied in northwestern San Joaquin Valley

An investigation by W. R. Hotchkiss, K. M. Scott, and G. O. Balding (r0754) showed that most of the fresh ground water in the Tracy-Dos Palos area (parts of San Joaquin, Stanislaus, and Merced Counties west of the San Joaquin River) is pumped from the Tulare Formation of Pliocene and Pleistocene age. An aquiclude, the Corcoran Clay Member, separates this formation into upper and lower water-bearing zones. Water from the upper zone is available within 20 feet of land surface in most places. The potentiometric surface of the confined lower zone generally is 5 to 20 feet deeper than that of the upper zone, but locally may be as much as 200 feet deeper.

The varied chemical quality of ground water in the upper zone is reflected in the lack of a predominant water type and in the range of dissolved solids (130 to 86,500 mg/l) in water samples collected. Limited data indicated that water below the Corcoran Clay Member has a higher average concentration of dissolved solids and is sodium chloride or sodium sulfate type.

#### Base of fresh water mapped in San Joaquin Valley

R. W. Page found that the base of fresh ground water in the San Joaquin Valley ranges in depth from near land surface to more than 4,000 feet. In some places, particularly on the west side of the valley, zones of fresh water underlie zones of water containing large concentrations of dissolved solids. Preliminary plotting of control points indicated that the interface between brackish water and the lowest stratum of fresh water forms a number of northwesterly trending crests and troughs. The crests and troughs, however, do not necessarily reflect the underlying geologic structure.

For the purposes of this study, fresh water was defined as that water having a specific conductance of not more than 3,000  $\mu\text{mhos}$  and a maximum concentration of dissolved solids of not more than 2,000 mg/l. Electric logs were used to interpret concentrations.

#### Hydrologic study of high-desert area

Preliminary findings in R. E. Lewis' study of geohydrologic data of the high-desert area of San Bernardino County indicated that: (1) the area is divisible into five separate hydrologic subunits separated by bedrock hills and by faults which act as barriers to



ground-water movement; (2) the largest amounts of ground-water withdrawals have been made in the sub-units which supply the towns of Yucca Valley and Joshua Tree; (3) ground-water withdrawals since 1958 have resulted in maximum water-level declines of about 40 feet near the town of Yucca Valley; (4) the concentration of fluoride in ground water is generally about 1 mg/l or less, but concentrations generally increase northward and, locally, at times exceed the maximum limits recommended by the U.S. Public Health Service; and (5) dissolved-solids concentrations range from less than 200 mg/l to nearly 2,000 mg/l near the old lake beds to the north, but the quality of water throughout most of the area may be described as good.

### NEVADA

#### Additional hydrographic areas investigated

In a continuing study, water-reconnaissance investigations of 16 of the 253 hydrographic areas in Nevada were completed during the year by P. A. Glancy (r2572) and A. S. Van Denburgh (r2583). Preliminary hydrologic budgets were compiled for each area. In 1969 studies were completed for the following areas: Adobe, Northern and Southern Alkali, Columbus, Hutton, Mono, Monte Cristo, Queen, Rhodes, eastern and western Soda Spring, Teels Marsh, and Virgin River valleys; Tule and Escalante Deserts; and Garfield Flat.

#### Walker Lake not expected to disappear

Walker Lake, a remnant of ancient Lake Lahontan, continued to shrink during the period 1919 through 1968. Despite an estimated average annual inflow of about 100,000 acre-ft, the lake stage had dropped to 3,970 feet in 1968, a decline of 105 feet since 1919. A study by F. E. Rush,<sup>47</sup> however, indicated that equilibrium will be attained when the stage reaches approximately 3,896 feet. In 1968 the lake had the following parameters: solute content, 2,240 mg/l; maximum depth, 118 feet; surface area, 38,000 acres; and volume 3,000,000 acre-ft.

### IDAHO

#### Quantitative studies show adequate water supplies in areas of southern Idaho

Of five areas within the Bear River basin of southeastern Idaho, the Malad River Valley offers the greatest potential for the development of additional ground-water supplies, despite local problems of water quality. According to W. L. Burnham, A. H. Harder, and N. P. Dion, a large aquifer system within unconsolidated alluvial material underlies about 75 square miles of the valley. This aquifer contains about 1.8 million

acre-ft of water in storage in the top 300 feet of saturated thickness and receives an average annual recharge of about 64,000 acre-ft. Net consumptive use of pumped ground water averages about 15,900 acre-ft annually. In general, water-level observations show that while the total demand on the ground-water resource may exceed recharge during dry years, over a long period, when recharge is normal, water levels will recover.

A water-resources study by E. G. Crosthwaite, C. A. Thomas, and K. L. Dyer found that the estimated total water yield of the Big Lost River Basin averaged 650 cfs for the period 1944–68. A distinctive feature of the basin is the large interchange of water from surface streams into the ground and from the ground into surface streams. The principal aquifer of the area is alluvial fill which yields as much as 3,500 gpm to individual wells. Geophysical studies show the fill to be more than 5,000 feet thick at some places in the main valley, but the nature of the material is unknown below a depth of about 300 feet.

The ground-water resource is adequate to supplement the surface supply for presently irrigated land and to irrigate new land. Improvements in water management might be accomplished by constructing reservoirs to control floods and by conjunctive use of surface water and ground water.

In the Portneuf River basin the major use of water is for irrigation. An investigation by R. F. Norvitch and A. L. Larson showed that the demand is met by diverting about 91,300 acre-ft of surface water annually, largely from the Portneuf River and its tributaries; importing about 14,000 acre-ft from the Bear River basin; and pumping about 30,000 acre-ft from alluvium, basalt, and the Salt Lake Formation. Measurements of water levels in wells indicate that as of 1969 the aquifers of the basin were not being overdeveloped.

Recent geophysical investigations suggested that the southern part of the Portneuf Valley is a structural trough that may contain as much as 8,000 feet of sediments. If these strata are porous and permeable, a copious supply of ground water is available in this basin.

### WORLDWIDE AND INTERREGIONAL STUDIES

#### World's water balance

Computations of the water balance of the world made by T. E. A. van Hylekama showed  $6.6 \times 10^{15}$  kg more water stored on land in March than in September. The extra seasonal storage in March occurs as snow and soil moisture in North America and northern Asia. Calculations, using tidal-gage records, showed

<sup>47</sup> Rush, F. E., 1971, Hydrologic regimen of Walker Lake: U.S. Geol. Survey Hydrol. Inv. Atlas HA-415. [In press]

$6 \times 10^{15}$  kg more water in the ocean in September than in March. The difference ( $0.6 \times 10^{15}$  kg) is contained in the earth's more humid atmosphere in September as compared to the dryer air in March. Changes in atmospheric pressure, ocean currents, winds, and shifts of moisture between land and sea cause a wobble in the earth's axis of rotation. This produces a variation in latitude as determined by astronomical observations, and the poles describe irregular circular patterns with a mean diameter of about 4 m. The magnitude of the deviation believed due to the shift of masses of moisture is of the order of 20 to 50 cm.

#### **Water-supply exploration on the public domain**

Water-supply investigations were completed during the year at 150 sites on public lands in Arizona, California, Colorado, Montana, Nevada, New Mexico, North Dakota, Oregon, South Dakota, Utah, and Wyoming by R. E. Smith, D. A. Webster, M. C. Van Lewen, M. S. Garber, and N. J. King. The U.S. Geological Survey's soil and moisture conservation program, carried on in cooperation with the U.S. Bureau of Land Management, provides technical assistance in the development of arid-land water supplies. Water is used as a range-management tool in protecting the public domain from overgrazing and erosion. Wells located by Geological Survey personnel are the usual source of supply, but spring development, stock-water reservoirs, or rainfall harvesting are alternative sources. At least 782 wells have been completed and 2,927 well-site evaluations have been made during the period 1941-67 as a result of this program.

### **SPECIAL WATER-RESOURCES PROGRAMS**

#### **SALINE WATER**

##### **Desalination**

The U.S. Geological Survey has expanded its concept of its responsibilities in water-resources investigations to place added emphasis on saline ground-water resources. A significant factor in this change has been brought about by the improving technology of desalination. Desalting costs have decreased from about \$5 per 1,000 gal in the early 1950's to less than \$1 per 1,000 gal for sea-water distillation in the late 1960's. For membrane desalting of brackish ground water (electrodialysis and reverse osmosis), costs now range from 40 cents to \$1 per 1,000 gal, depending on the salinity of the water. In most areas, water ready to drink can be taken from wells or surface-water filter plants for a few cents per 1,000 gal, but conveyance and distribution costs bring the householder's bill to the 25 to 50 cents per 1,000 gal charged by many cities

today. Subjective factors not generally shown by economic statistics appear to be gaining in importance in the use of desalination. Public health departments and informed consumers, in some areas, are aggressively demanding better water than Nature can provide at an economical distance from the point of use. In a computer survey of 18,000 cities and towns, the DuPont Co. determined that 1,150 communities serving a population of more than 3.5 million used water containing 1,000 mg or more of dissolved solids per liter. Though drinkable by a hardy person in concentrations of 2,000 mg/l or higher, water having a salinity above 1,000 mg/l becomes increasingly unpalatable and is defined as saline water in most reports of the Geological Survey.

In a paper presented at the American Water Resources Association symposium Water Balance in North America, F. A. Kohout (r2001) (U.S. Geological Survey) and M. F. Sachs (Office of Saline Water, U.S. Department of the Interior) discussed conveyance versus desalination as follows: "Redistribution of natural runoff can be accomplished on a vast scale, presently at lower cost than desalting provided that legal and other institutional impediments are overcome—but no 'new' fresh water is created. In contrast, desalting of previously unused onsite saline water creates completely controllable 'new' fresh water which over the long term can be expected to produce an increasingly substantial effect on the water balance of North America."

##### **Saline water—A valuable resource**

The rapid development of desalting technology brought with it the recognition of a new intrinsic worth for the pore space occupied by the saline water.

The natural-gas industry is making extensive use of saline aquifers to store gas near large metropolitan areas during the summer for later recovery during the peak-demand winter heating season. In much the same way, fresh-water "bubbles" can be temporarily stored in saline aquifers and later recovered; the feasibility of this technique was discussed by E. A. Moulder at the annual meeting of the American Geophysical Union in April 1969. In reporting on a test to inject a fresh-water "bubble" in a saline-water aquifer at Norfolk, Va., D. L. Brown reported that a decision was made not to use finished water from the Moores Bridges treatment plant, which is treated with calcium carbonate to reduce its acidity, but rather to use filtered but chemically untreated water. There are two advantages: the filtered but chemically untreated water has a lower turbidity than the finished water,

and the lower pH (about 5.8) will eliminate concern over the possibility of precipitation of calcium or magnesium carbonate where the host and injected waters meet.

The preliminary activities of the Federal Water Quality Administration have been directed to establishing standards of water quality for surface water. This increased awareness of surface pollution and of the need for protection of man's environment has greatly intensified interest in the use of saline aquifers for disposal, or storage, of toxic industrial wastes and other fluids. The data required for exploiting the saline ground-water system—by desalting, by storage of gas bubbles, by storage of fresh-water "bubbles," or by injection and subsurface storage of liquid waste—all tend to dovetail; the spatial distribution of saline water, the permeability variations of the rock, and the potential gradients and flow direction of the native saline ground water must be known. Without such knowledge, waste pumped into an aquifer that simultaneously is being used for some other purpose cannot be presumed to be permanently removed from the surface environment. To overcome the deficiencies of knowledge that now exist, the U.S. Geological Survey is proposing a major effort to map the total subsurface environment, to estimate the quantities of fresh and saline water available from it, and to provide a preliminary view of the feasibility of using certain regions of aquifer space for injection of liquid waste.

#### **Quantitative mapping of saline water**

At least half the United States is underlain by saline water at depths of less than 500 feet below land surface; in an additional fraction of the area, saline water is found beginning at depths somewhere below 500 feet. Permeable rocks extend to depths greater than 10,000 feet, but until recently little value has been placed on this vast region of "inner space" except for oil exploration, and little quantitative mapping of saline aquifers has been done. A cooperative pilot study between the U.S. Geological Survey and the Office of Saline Water, both of the Department of the Interior, has just been completed by T. E. Kelly for the Rio Grande region, Texas-New Mexico, an area of about 136,000 sq mi. Within the Rio Grande region, the physical factors of the Tularosa basin (about 4,000 sq mi) were studied by J. S. McLean (U.S. Geological Survey) and the economic factors by the New Mexico Water Resources Research Institute (NMWRRI) under the direction of H. R. Stucky. From the experience of these studies three categories of investigations appear to be necessary for proper water-resources

appraisal, for desalting, and for other forms of saline-aquifer utilization:

1. Regional studies, such as that of the Rio Grande—useful for broad regional appraisal and conceptual planning.
2. Subregional studies such as that of the Tularosa basin—useful for choosing specific areas where withdrawal of fresh or saline water, exploitation of mineralized zones, or injection of gas or fresh-water "bubbles" are possible, as well as for allocating aquifer space for waste storage.
3. Detailed site or feasibility studies—for confirming a tentative decision favorable to a particular utilization, before actual construction or use takes place.

F. W. Meyer reported a growing interest in saline artesian water and artesian aquifers in southern Florida. In the upper part of the Floridan aquifer in that area, large quantities of brackish water in the Avon Park Limestone are available for conversion to fresh water. As to the lower part, recently a well was drilled to a depth of 2,947 feet for the disposal of treated sewage effluent. The temperature of the water from 1,000 feet to 2,900 feet became lower with depth, an anomalous condition in view of the increase of temperature with depth normally to be expected from geothermal heat flow. Meyer reported that the temperature-salinity data support a hypothesis by F. A. Kohout that geothermal heating causes a pattern of circulation involving inflow of cold sea water from the Straits of Florida into the aquifer as part of a thermally motivated, convective system. Whether such a flow pattern actually exists awaits further proof, but the possibility that it does emphasizes the need for more adequate understanding of the aquifer system before extensive development for any purpose is undertaken.

T. M. Robinson reported that the Kings Hill Marl and associated alluvium in central St. Croix, Virgin Islands, receives about  $1\frac{3}{4}$  mgd of recharge (about 3 percent of the annual rainfall) and that 130 billion gal of brackish water is in storage. Of this, an estimated 35 billion gal could be economically withdrawn and desalted. At the projected population-growth rate, this water would be depleted in about 30 years. However, Robinson pointed out the possibility of injecting waste water treated to drinking-water quality, to augment the supply.

The influence of saline ground water on surface-water supplies was noted by P. R. Stevens. Saline springs and seeps issuing from Permian rocks in

Kansas, Oklahoma, and Texas account for about 54 percent of the salt load of the Arkansas and Red Rivers at the Arkansas State line. Most of this saline water was generated by the leaching of halite from the Permian rocks by circulating ground water. This leaching of salt is not limited to local systems of flow but may involve interbasin movement of saline water originating beneath the High Plains, in the Texas and Oklahoma Panhandles and eastern New Mexico.

P. H. Jones and R. H. Wallace, Jr., attempting to identify the effect of geologic structure on the occurrence of fresh ground water in Texas and Louisiana, reported that regionally the salinity of formation water in Tertiary deposits of the Gulf Coastal Plain is greatest at depths between 5,000 and 8,000 feet below sea level. Decrease in salinity below 8,000 feet is believed to result mainly from thermal diagenesis of montmorillonite to illite. In this process, bound water is released from the montmorillonite as free pore water, drastically reducing the load-bearing strength of clay particles and increasing the pore pressure of the interstitial fluid. The water under these conditions supports a major part of the weight of the overburden and the zone is said to be geopressed. Maps of the 180°F and 250°F isogeotherms define the depth at which thermal diagenesis of montmorillonite begins, and the depth below which formation-water salinity decreases progressively with increasing depth. Also, the 250°F isogeotherm commonly marks the top of the geopressed zone. In the coastal belt the geopressed zone begins at depths ranging from about 8,000 to about 16,000 feet.

## **DATA COORDINATION, ACQUISITION, AND STORAGE**

### **Office of Water Data Coordination**

Field-coordination procedures were initiated in the fall of 1969 to deal with plans of Federal agencies for water-data acquisition through fiscal year 1972. The initial effort was restricted to the acquisition of daily or continuous records of stage and (or) discharge at long-term surface-water stations. The objective of the initial activity was to test the coordination procedures through preparation of prototype regional plans and through preparation of a nationwide Federal plan, which would be submitted to the U.S. Bureau of the Budget in the fall of 1970.

Discussions regarding the National Water Data System were held with Federal agencies, and two work groups were established—a work group on standards for water-data acquisition and a work group on data handling. Membership consists of representatives of the agencies having an interest in specific areas. The standards work group is composed

of the chairmen of six task groups, which are concerned with (1) surface-water stage and quantity, (2) chemical and physical quality of water, (3) biological quality and presence of organic material in water, (4) sediment, (5) ground water, and (6) automatic water-quality monitors. The groups will select or develop standards for measuring, sampling, analyzing, and processing the data.

The level-1 accounting element of the national system was given field review, and ongoing station activities meeting network criteria were identified. The network measures the quantity and quality of surface water which leaves each of 306 hydrographic units in the conterminous United States. A list of the stations in operation which would satisfy the requirements of the network was compiled, together with a list of those stations which should be installed or which, though presently installed, require upgrading.

Indexes to the 1968 edition of the "Catalog of Information on Water Data" were published. The 1968 edition included the third update of surface-water stations and water-quality stations and, for the first time, a listing of ground-water stations and of areal investigations and miscellaneous activities. Updating of the surface-water, water-quality, and areal investigations and miscellaneous activities as of January 1, 1970, was completed. Summaries of the catalog content and statistical analyses of water-data acquisition were prepared from the catalog's table of contents.

The fourth meeting of the Federal Advisory Committee on Water Data was held in Washington, D.C., on February 13, 1970. The principal items discussed were the implementation of field coordination, work group activities, and the development of a Federal plan relating proposed activities to fiscal year and longer range objectives.

The fifth meeting of the Advisory Committee on Water Data for Public Use was held May 11–13, 1970, at which time the same general subject matter was covered as in the meeting of the Federal Advisory Committee on Water Data.

### **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 200,000 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:

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 30,000 ground-water wells and about 18,000 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 within the urban environment. Many new projects were started and on-going projects yielded significant findings. W. J. Schneider reported that an electromagnetic flowmeter has been obtained and will be tested in a storm sewer to measure flow under both open-channel and pipe-flow conditions. Development of a practical field method for measuring flow under both conditions is essential for collection of the kind of data necessary for storm-drainage studies.

#### Water resources of the Washington, D.C., area

A. M. Spieker and D. A. Rickert reported that a preliminary appraisal of the water resources of the metropolitan Washington area (District of Columbia, Maryland, Virginia) revealed a wide range of opportunities for the application of hydrologic data in urban comprehensive planning. They indicated that water data can be interpreted and presented for use by the urban planner in a form relevant to such problems as water supply, sewage treatment and disposal, erosion and sedimentation, flooding and storm drainage, solid-waste disposal, recreation, and improving the attractiveness of the environment.

Planning, with regard to water supply and the projected tripling of water demands by the year 2000, is based on the assumption that reservoirs will be built in the Potomac River basin. The present study suggests that three other sources can be con-

sidered as alternatives or as supplements to the proposed reservoirs. First, water could be taken from the Potomac estuary. Although this water is not of drinking-water quality, it could be treated to potable standards by currently existing methods. Second, ground water from limestone aquifers in the Potomac River basin could be pumped to augment the flow of the Potomac River, thus reducing the surface storage capacity required. Third, ground water from the Coastal Plain aquifers of Maryland and Virginia could yield about 100 mgd to supplement the metropolitan supply. This last source would probably be sufficient to relieve the strain on the Potomac River supply during critical drought periods for about the next decade. Artificial recharge could substantially increase this yield. Ground water could be pumped at rates in excess of natural recharge during the dry periods when the greatest water demands generally occur. The aquifers could then be recharged during periods of abundant rainfall. Highly treated sewage effluent might be regarded as an additional source of recharge. An integrated three-way system utilizing both surface and underground sources of supply would offer a flexibility for alternative management practices which would not be available in a single-source system.

#### Studies of urban runoff and floods

*Texas.*—An increasing awareness of problems created by urban sprawl led to the establishment of data-collection networks in Texas that are designed to provide data necessary for the solution of these problems. Urban water studies in seven areas are currently underway by the U.S. Geological Survey in cooperation with State and local agencies.

The broad objectives of these projects are to determine the effects of urbanization on the quantity, quality, and mode of occurrence of storm runoff. Trigg Twichell and various members of his technical staff found that these projects are obtaining much secondary information in addition to that which satisfies the primary objectives.

A preliminary rain-gage density analysis of a network in Dallas, Tex., indicated that intelligent design is necessary to obtain reliable storm-rainfall data. A comparison of the weighted-mean rainfall from five gages in the Turtle Creek watershed with records from three single rain gages in two adjacent watersheds showed significant variability for storms of greater than 0.3 inch during a 4-year period. At the 67-percent confidence limit, the standard error of estimate, adjusted for three lost degrees of freedom, varied from +30.0 percent and -23.0 percent to +49.1 percent and

—32.0 percent. During the same period, a comparison of weighted-mean rainfall from five gages with the weighted mean of only two of these gages showed a standard error of estimates of +6.7 percent and -6.2 percent. This finding leads to the conclusion that the proper design of a rain-gage network has much greater significance than merely refining instrumentation to the capability of recording rainfall to thousandths of an inch.

In the Bryan, Tex., study area, the paired watershed (one rural and one urban) concept is being used. After 2 years of rainfall data collection, it has been observed that one of the three rain gages in the rural watershed, all having excellent exposure, may be located in a partial rain shadow of the tall trees along the stream channel. This gage has recorded about 7 percent less annual rainfall than the average of the other two rain gages in the watershed during the period of record. The maximum distance between rain gages is about 1.7 miles.

An attempt to reduce the quantity of computer output to an amount suitable for a basic-data report is being tested in the Dallas urban program. Data from analog charts are being coded in skeletonized form. The computer interpolates between the selected points, thereby producing a set of data suitable for program input, but at the same time retaining the original data in a condensed form, which can be included in a basic-data report. Because of the poor quality of the computer printout material, the problem of the production of legible photocopies remains to be solved.

The present state of the art of data analysis requires digitalized data for computer processing; however, the present digital recorder used at hydrologic stations can record only to 5-minute intervals. This interval is inadequate for small study areas. Up to this time, data have been collected with a single-recorder system when a two-recorder system is needed to collect the data in usable form.

Efforts in Texas to collect data adequate for producing an inflow hydrograph and a rainfall mass curve from a small, controlled, completely sewerded, highway undercrossing in San Antonio have again illustrated the fact that present-day instrumentation is inadequate for extremely small-area studies. With a Stevens A-35 recorder equipped with a 28.8-in.-per-day chart drive, the apparent chart readability is 30 seconds; however, the skew of the reversal-test line may change by an amount greater than 30 seconds during the 28 days between chart changing. For studies of this type, the instrument needs to be equipped with a chart-aligning device.

At Houston, Tex., S. L. Johnson and D. M. Sayre

found that in many of the areas flood frequency and magnitude are greatly influenced by basin storage which occurs because of drainage-network design or because receiving channels become inadequate. Deliberate street and overbank detention of storm runoff is sometimes used to regulate inflow to the larger streams, thus reducing downstream flooding. The flat topography of the area permits large volumes of water to be temporarily stored in streets and drainage structures without property damage. Determining the effects of this storage on peak runoff rates is one of the major problems under study. This must be solved before data collected from these areas can be used to establish meaningful relationships which can be used for design of new or improved drainage systems.

Preliminary analysis of the collected data indicates that the multiple-linear regression technique and the Dawdy rainfall-runoff simulation model offer possible modes of development for pursuing the objective of the study.

In six to seven of the study areas, the effects of urbanization appear to reduce the time to peak and to increase the magnitude of the peak discharge.

A cursory review of the water-quality data collected during the year showed concentrations of chlordane of as much as 8.0  $\mu\text{g}/\text{l}$  and concentrations of toxaphene of as much as 7.0  $\mu\text{g}/\text{l}$  from point samples in streams. These concentrations are well above the acceptable standards for public water supply, however, neither of the streams is used for water supply. A report on these and other water-quality data is in preparation.

*Virginia.*—Continued progress has been made in flood-plain mapping in Fairfax County, Va. F. P. Kapinos reported that during the current year 124 flood-inundation maps were prepared for 2 drainage basins (drainage areas of 34 and 51 sq mi), bringing this portion of the project to 33-percent completion. The large-scale maps (1:1,200, contour interval 2 feet), have been prepared in cooperation with the Fairfax County Department of Public Works in order to help local government officials control encroachment into potentially hazardous flood areas. A recent report by D. G. Anderson on the effects of urbanization on flood flows was used as the basis for determining design discharges for 25-, 50-, and 100-year recurrence intervals under conditions representing ultimate development. Recent large floods in one of the completed basins has permitted direct comparisons between actual and computed flood profiles. In most instances, the actual flood profiles follow very closely those computed by indirect methods.

*Arizona.*—H. W. Hjalmarson and L. L. Werho found that flood hydrographs from an 81-acre urban water-

shed near Phoenix, Ariz., can be synthesized using unit hydrograph principles. Two infiltration curves are required to define precipitation excess—one curve for the impervious or “paved” area, and one curve for the remaining area. Typical of a simulated peak is the flood of December 10, 1965; the simulated peak discharge was 8 percent less than the measured peak discharge, and the simulated flood volume was within 1 percent of the measured volume.

*California.*—S. E. Rantz reported that during the disastrous flood of January 1969 in southern California, the greatest physical damage occurred in areas of urban sprawl. In those areas, zoning ordinances do not minimize the hazards of inundation and debris or landslide damage, and drainage and flood-control facilities are not fully developed. On the other hand, damage was minimized in the older urban areas where adequate drainage and flood-control facilities exist. In Los Angeles County, for example, total physical flood damage, in dollars, in January 1969 was only 60 percent of that incurred in March 1938 during a major flood of equivalent intensity. The reduction in damage effected by flood-control facilities built since 1938 is striking, in view of the fact that urban development was much more widespread in 1969 than in 1938, and that the purchasing power of the dollar was much lower in 1969.

#### Hydrology of sanitary landfill sites

G. A. Brown reported that a study of a proposed solid-waste disposal site near Woodbridge, Va., revealed two sand and gravel aquifers in Lower Cretaceous unconsolidated sediments. The site is on tidal marshes and sloping land along the Potomac River and is in the recharge area of Lower Cretaceous sands and gravels from which nearly 2 mgd of water is pumped 5 miles to the east at Indian Head, Md. Test drilling at the site showed a 200-foot thickness of sediments overlying an amphibolite-chlorite schist basement; the sediments are known to thicken eastward to 600 feet at Indian Head. The two aquifers at depths of 84 to 114 feet and 146 to 184 feet are separated by a low-permeability silt and are also covered by 84 feet of silt and clay layers which prevent intermingling with surface water. Observation wells were constructed in each aquifer; one was screened from 95 to 105 feet and the other from 156 to 176 feet. Analysis of 8-hour pumping tests showed no interconnection between the aquifers and yielded coefficients of transmissibility of 3,150 and 2,100 gpd per ft for the upper and lower zones, respectively. Water from both aquifers is low in dissolved-solids content except for a high iron content

of 0.22 mg/l in the lower aquifer, compared with 0.09 mg/l in the upper aquifer.

J. W. Stewart and others are conducting a study in Hillsborough County, Fla., to determine the effects on water resources of disposing solid waste into trenches excavated below the water table in a sand and silt aquifer overlying a limestone aquifer. Sites were placed in operation in November 1969 and February 1970, and represent the following contrasting geologic and hydrologic conditions: (1) a low, swampy area having sands and clays 20 to 30 feet thick, water table less than 5 feet below land surface, and a potentiometric surface in a limestone aquifer sufficient to cause water to flow at land surface, and (2) a high well-drained area adjacent to a stream and having sands and clays 30 to 50 feet thick, a water table 5 to 15 feet below land surface, and a potentiometric surface below the water table except near the stream channel where wells drilled into limestone flow at land surface. Test holes were augered at both sites to determine the hydrology and geology of the materials at the landfills, and to establish a network monitoring system for periodic sampling of water from the artesian and nonartesian aquifers. Additional sampling sites included oxidation ponds, canals, perimeter ditches, and landfill trenches. Data collected to date at the site established in November 1969 have not indicated any contamination of the surface and ground water in the area.

#### Urban water-resources studies

*Long Island, N.Y.*—G. E. Seaburn (p. B196–B198) reported that a comprehensive study of recharge basins on Long Island provided information on the apparent rates of movement of water through the zone of aeration. Pertinent data were collected during 38 storms from a basin in central Nassau County, Long Island, N.Y. where the depth to the water table is 35 feet below the bottom of the basin. Beneath this basin the apparent downward rate of water movement averaged 5.0 ft per hr; it ranged from an average of 3.0 ft per hr for storms in November through March to an average of 6.0 ft per hr for storms in April through October.

*California.*—J. A. Moreland made a study to evaluate the feasibility of artificial recharge in the Yucaipa basin in San Bernardino County, Calif., and identified and evaluated seven ground-water subbasins as potential recharge sites. The study indicated that artificial recharge of 6,000 acre-ft per yr should be possible in Wilson Creek subbasin using existing flood control basins as spreading grounds. Extraction wells can be located near sites of expected urban development. The study showed that an unlined reservoir at the Yucaipa



Dam site would be difficult, if not impossible, to fill owing to high infiltration losses.

*Massachusetts.*—J. E. Cotton and D. F. Delaney reported that in the last 30 years there was practically no long-term change in the water-table altitude or in ground-water storage in the central Boston area in Massachusetts. Relative stability of the water table is essential in landfill areas of central Boston, for structural damage to older buildings may result from deterioration of wooden foundation piling if the water table is lowered. Very little ground water is now pumped in the area. Changes in the configuration of the water table result largely from changes in amount and distribution of recharge, leakage of ground water into sewers and storm drains, and pumping from excavations extending below the water table. Annual precipitation for 1936–40 ranged from about 9 inches below to 9 inches above the average precipitation of 41.4 inches. Maximum and minimum water-table altitudes for this period were used for comparison with recent data. The autumn low water table for 1967 was higher than the 1936–40 minimums; the spring high water table of 1968 ranged from below to slightly above the 1936–40 maximums.

*Florida.*—Continuing studies in Dade County, Fla., are chiefly concerned with urban water problems. J. E. Hull (r2495) and C. F. Galliher reported on changes in hydrologic conditions during 1966, 1967, and 1968; and F. W. Meyer has prepared a series of average water table maps for use in updating flood-control criteria. Meyer estimated that the amount of fresh water discharged to the ocean by sewage treatment plants in Dade County will increase from 84 mgd in 1969 to 330 mgd in 2000.

H. G. Stangland, Jr., studied lakes in the Walt Disney World area near Orlando, Fla., and sampled them during August and September 1969. They were generally found to be shallow (10–15 feet deep) and to have acid water and little or no thermal stratification. However, these preliminary water-quality data indicate differences in water quality between nearby lakes. The secchi disk readings varied from 1 to 8 feet, indicating a wide variation in turbidity. Conductivity readings ranged from 51 to 123  $\mu$ mhos, and pH ranged from 4.5 to 6.6. Dissolved oxygen generally decreased only slightly with lake depth but decreased significantly with depth in two lakes. In these two lakes the dissolved oxygen was less than 3 mg/l near the bottom.

The stream water-quality data obtained in the area thus far indicate high concentrations of nutrients (1 mg/l total N), color (200–400 units), but low concentrations of hardness (10–30 mg/l), pH (4–6), and

chloride (10–15 mg/l). Dissolved oxygen has been below 3 mg/l in hyacinth-choked channels and in small tributary streams when the discharge approaches zero. Total coliform bacteria in the streams ranged from 3,400 to 16,000/100 ml in September and from 500 to 940/100 ml in November. The 5-day biochemical oxygen demand was generally less than 1 mg/l, but ranged from 0 to 3.9 mg/l. There was no significant trend between the September and November biochemical oxygen demand. Initial macroinvertebrate samples indicate that several environment-sensitive type organisms are present in the streams and lakes; these may be usable as indicators of water-quality changes in the area. The sensitive organisms consist of several species of caddisflies and midges, as well as sensitive species of dragonfly, damselfly, black fly, and mayfly.

#### **Sediment and erosion from urban areas**

J. M. Knott reported that the sediment yield of Colma Creek, a tributary to San Francisco Bay, has been strongly affected by construction activities related to urbanization. Nearly 20 percent of the drainage basin is under development. In 1969 and 1970, simultaneous measurements of total-sediment and water discharge were obtained at subbasins representing native vegetation, stable urban conditions, and unstable development conditions, and at a downstream gaging station on Colma Creek. Annual sediment yields for changing land-use patterns will be estimated from sediment records at the Colma Creek gaging station, from land-use maps, and from subbasin relationships. Preliminary data indicate that sediment yield in stable urban areas is on the order of 4 to 8 times the yield in native vegetation areas but only about one tenth that in unstable development areas.

Studies made by T. H. Yorke and W. J. Davis III indicated that the sediment load from an urbanizing drainage basin in Montgomery County, Md., between March 1965 and August 1967 was more than 14 times that which would have occurred had the basin remained in its natural state. Intensive development of the Bel Pre Creek basin was started in March 1965, and by August 1967, 190 acres had been converted from woodland and pasture to a complex of garden apartments and townhouses and another 150 acres was in the construction stage. This amounted to 31 percent of the basin and resulted in a substantial increase in the concentration of suspended sediment and the amount of storm runoff. Comparison with a nearby control basin indicated that under natural conditions about 450 tons of suspended sediment would have been transported by the stream during the 30-month period.

The suspended load transported between March 1965 and August 1967 was about 6,400 tons.

A unique combination of substantial channel change and documentation of the changes by high-order photogrammetry in Tujunga Wash in southern California is reported by K. M. Scott. Extensive scour and fill occurred during the 1969 floods in this 3-mile-long, partly urbanized fanhead valley. Maximums of about 20 feet of net scour and 35 feet of net fill were measured on 31,000 scale feet of cross sections plotted to illustrate changes in distributary channels of the wash. In the channel profile, 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 yet probably natural diversion of floodflow to a major distributary channel of the wash in which 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 because of, among other causes, natural adjustment of a distributary channel to flood discharge. An entire residential street, seven homes built on an unstabilized cutback of the channel, and three bridges were destroyed as the combined result of these factors. Additional scour and fill were due to natural, lateral shift of channels in broad, ephemeral washes and to locally raised base level. Damage in most, if not all, of the cases could be ascribed to man's disregard of natural geomorphic processes on alluvial fans and in fanhead valleys.

#### Urban effects on lakes

*Virginia.*—D. A. Rickert reported on the impact of urbanization on the water quality of Lake Anne, a 30-acre 6-year-old manmade lake in Reston, Va., near Washington, D.C. A reconnaissance of Lake Anne suggested that potential urbanization effects might include sediment accumulation, eutrophication, degraded sanitary quality, and pesticide accumulation.

Preliminary results based on comparison of water quality in Lake Anne with that in a nearby undeveloped manmade lake (Lake Elsa, 30 acres, 15 years old) and collection and comparison of limited monthly and seasonal data in Lake Anne indicate that both sediment and mineral water-quality problems are developing at Lake Anne. Sedimentation has claimed a considerable, but yet undefined, portion of the initial storage capacity of the lake. Nutrient analyses during October 1969 indicated that the total inorganic nitrogen and phosphorous concentrations were about 0.45

and 0.06 mg/l, respectively, in Lake Anne, while the corresponding values were 0.21 and 0.02 mg/l in Lake Elsa. Thus, two times as much nitrogen and three times as much phosphorous were available for algae growth in Lake Anne than were available in Lake Elsa.

Low organism densities for total coliform, fecal coliform, and streptococcus coliform bacteria indicated that the sanitary quality of water was excellent in both lakes. The lack of contamination of the lakes by domestic waste was further confirmed by the low values for the ratio of fecal coliform to fecal streptococcus ( $<0.4$ ), and also by the complete absence of methylene blue active substances (primarily detergents) in either lake.

No insecticides were detected in either the water or the sediment from Lake Elsa. In Lake Anne, however, DDT at a concentration of 0.10  $\mu\text{g/l}$  was detected in the water while DDE at 2.3  $\mu\text{g/kg}$  was detected in the sediment. Only one sample each of water and sediment was tested from Lake Anne. The 0.10  $\mu\text{g/l}$  of DDT is two times the 0.05  $\mu\text{g/l}$  value which many wildlife biologists believe should be the maximum acceptable value in water for fish propagation. DDE is commonly found in sediment where it forms as an anaerobic breakdown product of DDT.

*Minnesota.*—W. B. Mann IV and T. C. Winter reported that a water budget is being prepared for Lake Sallie as part of a major research project to develop methods and techniques for control of accelerated eutrophication. Lake Sallie is located in Becker County, Minn. Preliminary analysis, by Winter, of the ground-water data collected during the first year of the study indicated a year-round movement of ground water toward Lake Sallie. A digital model of the ground-water system is being prepared by M. S. McBride to define the ground-water flow patterns and calculate ground-water contribution to Lake Sallie. Preliminary analysis, by Mann, of surface-water data from gaging stations measuring inflow to and outflow from St. Clair Lake, tributary to Pelican River just upstream from Lake Sallie, indicated that the ground-water contribution to St. Clair Lake is about 1 cfs on the average. During the coming year, three observation wells will be installed in an attempt to verify this apparent ground-water movement to the lake. Chemical quality of the surface water entering and leaving the area have not shown any significant changes during the past year.

*Washington.*—Eutrophication of lakes from nutrients is usually considered a function of the density

of lakeside dwellings. However, samples of lake water taken by M. R. Collings and G. T. Higgins showed that nutrient level is not a function of resident density only. From the first sampling of 22 lakes in the State of Washington, comparisons between phosphate concentrations and the basin characteristics revealed that a few lakeside residences in one area may do more harm than many in another. For example, at Hancock Lake, in a forest area, there are 14 dwellings with outdoor toilet facilities and a shoreline of 2.75 miles, the total phosphate concentration was 0.13 mg/l. In contrast, at Clear Lake, also in an area of evergreen vegetation, there are more than 100 dwellings with indoor toilet facilities and a shoreline of 2.1 miles, but the total phosphate concentration was only 0.02 mg/l. Another example of two lakes with similar basin characteristics but different nutrient levels resulting from surrounding population levels is Tanwax Lake, approximately 200 residents, total phosphates 0.05 mg/l, and Silver Lake, 34 residents, total phosphates, 0.16 mg/l.

Preliminary conclusions are that, in addition to depending on the number of lakeside dwellings, the buildup of nutrients also depends on the seasonal or continuous residence in the dwellings, the type of waste-disposal facilities, the depth to the water table at points of disposal, the local pattern of ground-water movement, the permeability of the soil and rock materials, and the operating age of the disposal systems.

### WATER USE

#### Tables of water use in the United States by subregions

Although water-use information in the United States has been compiled for approximately 270 subregions, as determined by hydrologic and State boundaries, the information has been combined in published U.S. Geological Survey Circulars into approximately 20 hydrologic, water-use regions or into approximately 50 State units. To supply the need for more detailed information, C. R. Murray prepared tables of water-use data for the 270 subregions. The latest data available on this scale were for the year 1965. Only a few copies of each table have been produced thus far by the U.S. Geological Survey for supplying official requests. The tables as prepared present water use by (1) States and categories of use, or (2) categories of use and States. However, by rearranging the data, tables of water use by (1) major water-use areas and categories of use or (2) categories of use and by major water-use regions can be obtained.

#### Rapid development of ground water in the Arkansas River valley of Colorado

T. J. Major, R. T. Hurr, and J. E. Moore (r2574), who made a hydrogeologic study of the lower Arkansas River valley of Colorado, found that ground-water use, as a supplemental irrigation supply, increased substantially between 1950 and 1965. During this 15-year period, about 1,000 wells were drilled. There were 1,300 irrigation wells in the valley in 1965. Annual withdrawal of ground water during the period ranged from 31,000 acre-ft to 185,000 acre-ft. The annual average was 65,400 acre-ft for the first 5 years and 144,000 acre-ft for the last 5 years.

#### Water use in southeast Iowa

R. W. Coble reported that more than 246 mgd of water was withdrawn for all uses during 1969 in an 11-county area in southeastern Iowa. A water-use study made as a part of a water-resources investigation revealed that the generation of electric power accounted for nearly half the withdrawals but for only 6 percent of the water consumed. In contrast, rural uses constitute withdrawals of only 16.5 mgd, less than 7 percent of the total, and yet are responsible for an estimated 65 percent of the 19.3 mgd of water that is consumed.

The surficial and shallow bedrock aquifers are readily replenished by recharge from local precipitation. However, the deep-lying Cambrian-Ordovician aquifer in this area is replenished only by water moving laterally through it from the northwest. Water in this aquifer moves into southeast Iowa at an estimated rate of only 3.2 mgd, whereas withdrawals from it now average 9.6 mgd. The deficit is made up by water withdrawn from storage which accounts for the regional lowering of the piezometric surface from 50 to as much as 100 feet since pumping from that aquifer began more than 70 years ago.

#### Public-supply and water-use inventories in Louisiana

Information on public supplies and water use by parish was collected by D. C. Dial. Information on public supplies includes source of supply, population served, pumpage, and water quality. Subsurface hydrologic data include driller's logs, electrical-log interpretations of fresh-water-bearing sands, sieve analyses of sand samples, and aquifer tests. Pumpage of public water for Louisiana is summarized according to the source of supply. Other categories for which pumpage was determined are industrial, fuel electric, rural domestic and livestock, and irrigation. The quantities are broken down according to the amounts of surface and ground water and the parish in which they are used.

### **Use of ground water for irrigation in Seward, York, and Hamilton Counties, southeastern Nebraska**

J. M. Jess (Conservation and Survey Division, University of Nebraska) found that 42,000 acre-ft of ground water was withdrawn for irrigation in 1969 in Seward County (west of Lincoln, Nebr.). The principal crop grown was corn. In the previous year it was determined that 540 wells had yielded an average of 76.8 acre-ft per well. The depth of water applied during the year averaged 10 inches, with well yields ranging from 285 to 1,520 gpm. Irrigated cornfields yielded an average of 115 bushels per acre compared with 60 bushels for dry farming. Water levels have declined 3 to 5 feet since extensive ground-water development for irrigation began in the late 1950's.

E. K. Steele determined the production and other properties of irrigation wells in 1969 in York County (west of Seward County). The average discharge of 30 wells tested was 820 gpm, and the average number of hours pumped for 62 wells on which records were kept was 658 hours. Water withdrawn from individual wells ranged from 13 acre-ft to 252 acre-ft, the average withdrawal being 102 acre-ft. The depth of water applied per acre ranged from 3.0 to 38.2 inches, the average was 16.2 inches. As a result of above-average recharge from precipitation in 1969, water levels in observation wells were 0.44 foot higher on the average, when measured during the autumn, than they were in the previous year.

Steele's study of irrigation wells in Hamilton County (west of York County) determined that the average discharge of 40 wells was 837 gpm and the average time each was pumped for the year was 679 hours. The quantity of water withdrawn from the wells ranged from 23 to 248 acre-ft, the average withdrawal being 108 acre-ft. The depth of water applied per acre ranged from 2.75 to 31.1 inches, the average was 14.2 inches. It was estimated that 197,000 acre-ft of water was withdrawn throughout the county for irrigation in 1969. Comparison of water levels in observation wells measured in the fall of 1969 and 1968 showed an average decline of 0.33 foot during the year.

### **Use of ground water for irrigation in Klamath Basin, Oreg.**

Recent field studies by A. B. Harris and A. R. Leonard showed that the number of irrigation wells in the Klamath Basin tripled since 1955. In the fall of 1969, some of the previously flowing wells in the western part of Klamath Marsh ceased to flow, and the yield of others declined substantially. The lowered artesian pressure, which causes the declining yields, may result

from cyclic climatic effects, increased pumping, or a combination of the two.

### **INTERNATIONAL HYDROLOGICAL DECADE, 1965-74**

R. L. Nace continued his activities as chairman of the international Working Group on the World Water Balance—one of the principal working groups of the International Hydrological Decade (IHD)—and presented a paper on this subject at the mid-decade conference. He and Alfonso Wilson each prepared papers for presentation at the Symposium on the World Water Balance to be held shortly after the end of fiscal year 1970 in Reading, England.

R. H. Brown served as a member of a panel of experts and helped to prepare a guide for ground-water studies to be published by the United Nations Educational, Scientific, and Cultural Organization (UNESCO). G. W. Whetstone participated as a member of a panel of experts and as coeditor in the preparation of a state-of-the-art report on systems for acquisition, transmission, and processing of hydrological data, also to be published by UNESCO.

H. E. Skibitzke helped to plan evapotranspiration studies and participated in a preliminary investigation of the occurrence of ground water in Lake Chad, west-central Africa. A. E. Robinson supervised the establishment of an electronic laboratory and the design of an electronic analog model for the Chad Basin.

Wilson met with high government officials in Mexico and in several countries of Central America to encourage participation in the IHD.

R. L. Cory continued water-quality monitoring and studies of epifauna in three small estuarine tributaries in Maryland—South River, Rhode River, and West River—on the west side of Chesapeake Bay, in Anne Arundel County, roughly due east of Washington, D.C. Allen Sinnott made preliminary studies of the net change in bathymetry in the Rhode River estuary, based upon worksheets of U.S. Coast and Geodetic Survey navigation charts dating from 1876.

M. F. Meier, L. R. Mayo, W. V. Tangborn, A. S. Post, W. J. Campbell, and L. A. Rasmussen conducted studies which appear in the section on glaciology (p. A140-A141).

Deric O'Bryan, M. E. Cooley, and T. C. Winter completed their field studies of late Holocene epicycles of alluviation, arroyo cutting, and terracing along parts of Chinle Wash and its tributaries in northeastern Arizona. Their work is reported in the section on geomorphology (p. A147-A148).

A compendium of chemical-quality and sediment data for selected river stations was compiled by the U.S. Geological Survey for UNESCO and titled "Sum-

mary of Water Quality Data for International Hydrological Decade River Stations in the United States." Wilson and G. A. Billingsley compiled data for a UNESCO volume, "Yearbook of Discharges of the Main Rivers of the World."

A 1969 revision of the 1967 Hydrologic Investigations Atlas 282 carrying the slightly modified title, "River Discharge to the Sea from the Shores of the Conterminous United States, Alaska, and Puerto Rico," was compiled by Wilson and K. T. Iseri. R. F. Hadley compiled information for a volume entitled "Decade Representative and Experimental Research Basins in the United States," which was published by the U.S. National Committee for the Hydrological Decade. E. C. Rhodehamel, V. B. Kron, and V. M. Dougherty prepared a bibliography of articles published through 1966 involving the use of tritium in hydrologic studies.

W. H. Monroe (1961) prepared a glossary on karst terminology which was published in the Water-Supply Paper series of contributions to hydrology.

## MARINE GEOLOGY AND HYDROLOGY

### MARINE AND COASTAL GEOLOGY

Population growth, urbanization, and industrial expansion, though rapid over the whole Nation, are increasing along the coastal zone at rates far in excess of those of the national average. At the same time, increased demands for consumer goods are placing ever greater emphasis upon the Continental Shelf as a new source for mineral raw materials. These increased and often competitive demands for use of the Nation's continental margins have generated problems whose proper solution is urgent. Marine geology and hydrology play a fundamental role in solving these problems.

Efficient use of this coastal zone is dependent on an understanding of how the various uses will be affected by, or will act upon, the geologic and hydrologic processes constantly at work. The stability of coastal and sea flood sediments in areas of urban expansion, the potential of specific coastal areas for damage from landslides, earthquakes, tsunamis, or hurricanes, the ability of sediment-laden water to accept pollutants and yet retain its biological viability, and the possible imbalance of the ecosystem as a result of subsea mineral exploitation are all problems requiring a knowledge of the geologic environment.

The identification of a mineral resource on or beneath the sea floor and the determination of its potential value are also dependent on a knowledge of the geologic history of the continental shelves and the deep ocean. As land sources are depleted, in-

creased utilization of subsea minerals will be required just to maintain our normal technological growth, much less to keep pace with the requirements of a rapidly expanding population and economy. Knowledge of the geologic environment is necessary to evaluate the public worth of developing a resource in relation to other uses of the sea bed.

The U.S. Geological Survey (USGS) has been conducting investigations, since 1962, to assist in solving these complex problems. Studies are underway on the Atlantic, Gulf of Mexico, Pacific, and Alaskan continental margins and elsewhere. Some of these studies are pursued under research contracts with universities and oceanographic institutions, and others are conducted under cooperative arrangements with such Federal agencies as the Coast and Geodetic Survey, Bureau of Commercial Fisheries, Naval Oceanographic Office, and Coast Guard. Results of the past year's research programs in marine geology and hydrology are summarized below.

### ATLANTIC CONTINENTAL MARGIN

Data acquired in previous years were analyzed to define the general distribution and composition of the sediments of the Atlantic Continental Shelf and Slope and to identify the major processes that governed this distribution. The rising demands for sand and gravel sources for construction in the highly urbanized northeastern coastal area make these studies of economic as well as scientific importance. More detailed geophysical and sedimentologic studies in the Gulf of Maine and other areas continued in cooperation with Woods Hole Oceanographic Institution (WHOI) and Duke University under research contract, and with the U.S. Bureau of Commercial Fisheries (BCF), U.S. Coast Guard, and U.S. Bureau of Sport Fisheries.

#### Sediment texture on the continental margin

J. S. Schlee's studies of sediment texture showed that the continental margin of the Northeastern United States is covered mainly by fine- to medium-grained quartzose sand out to the shelf edge, and by silt and clay on the continental slope and rise. On the glaciated part of the Continental Shelf (Gulf of Maine), the sediment is mainly composed of till-like mixtures of sand, gravel, silt and clay; in basins in the Gulf of Maine, pelagic silty clay veneers older glacial deposits. Adjacent to the rocky shelf around Nova Scotia, coarse gravel is common.

Deposits of coarse cobbles and boulders occur mainly in the Gulf of Maine and particularly as lag deposits on banks and ledges, due mainly to winnowing

of these elevated areas by bottom currents. The southern limit of glaciation is marked by a fringe of gravelly sand and sandy gravel that stretches from Martha's Vineyard and Nantucket, southeastward across Nantucket Shoals and Great South Channel and along the northern part of Georges Bank. The shelf south of the glacial limit is mainly a sand-covered plain transected by wide channels and carved by a dendritic drainage pattern southeast of New York and New Jersey. Redistribution of sandy debris on Georges Bank and the inner shelf elsewhere was so prevalent that channelways are now buried, though they can be detected on continuous seismic profiles.

Sediment-texture studies by C. D. Hollister (WHOI) of the continental margin from New Jersey to southern Florida show that bottom currents play a major role in governing textural parameters. Bottom currents have reworked sediment on the Continental Shelf and Blake Plateau to the extent that many surface samples from these two distinct provinces are similar. The continental slope off Florida is covered with a prograding accumulation of poorly sorted clayey silt deposited beneath the Gulf Stream countercurrent. A distinctive accumulation of silty sand on the southern margin of the Blake Plateau is probably winnowed pelagic ooze transported from the eastern Blake Plateau by the Antilles current. Well-sorted sand is found beneath the axis of the Gulf Stream in the Florida Straits and on the Blake Plateau. North of the Blake Plateau, where the Gulf Stream touches the bottom in deeper water, a marked increase in silt and sand is found.

The clayey, hemipelagic silt found on the continental slope north of Cape Hatteras was deposited beneath the sluggish, southerly moving slope water. The silty clay on the upper continental rise off Maryland and New Jersey accumulates in the relatively tranquil region that lies between the slope water and the deeper, more vigorous western boundary undercurrent.

#### **Sediment types of the central and southern margin**

Sediments on the Continental Shelf and Slope south of Long Island, N.Y., were classified into nine sedimentary groups by J. D. Milliman (WHOI): (1) fine-grained clear arkosic to subarkosic sands and silts; (2) iron-stained subarkosic sands; (3) coarse- to medium-grained subarkosic-orthoquartzitic sands with less than 25 percent calcium carbonate; (4) orthoquartzitic sands with 25 to 75 percent carbonate; (5) carbonate-rich orthoquartzitic sands, containing large amounts of barnacle fragments, oolite, and coral reef debris; (6) carbonate-poor slope muds; (7) glauconitic slope sands; (8) carbonate-rich slope muds; and (9) planktonic carbonate sands and gravels from the Blake

Plateau. From the presence of fossils within many of the sediment groups on the shelf, it has been concluded that the Continental Shelf is generally an environment of nondeposition. Much of the continental slope and the Blake Plateau also are areas of nondeposition and have not accumulated sediment since the Miocene. Clearly then, any sediments debouching onto the slope off Georgia or South Carolina must be swept north by the Florida Current. As such, this sediment may account for a significant sediment accumulation in the deep sea northeast of Cape Hatteras.

#### **Southern shelf sedimentation**

After examining more than 2,500 sediment samples from the shelf, beaches, rivers, and estuaries, O. H. Pilkey (Duke University) and J. D. Milliman (WHOI) concluded that the three main sources of surficial shelf sediment are rivers, calcareous skeletal material, and subaqueous outcrops of coastal plain strata. Fluvial material is most important. The sediment is, for the most part, derived directly from the Piedmont province. The rate of terrigenous sedimentation has been highest off Georgia and decreases to both the north and south. Lateral transportation on the shelf has not been important.

At the present time, deposition is occurring only in a narrow nearshore band and beyond the shelf break. Present-day rivers are contributing only very small amounts of sand, and a significant portion of inner shelf, beach, and estuarine sands are derived from the central and outer shelf.

Probably 90 percent of the shelf is covered by relict sediments, which are now being winnowed. These relict sediments were originally laid down in the inner-shelf environment; relict beach sediments are quantitatively unimportant. The relict sediments were deposited mainly during the last transgression. Locally, however, a significant portion of the sediment was deposited during the last regression.

#### **Calcium carbonate on the southern shelf**

J. D. Milliman (WHOI), O. H. Pilkey and B. W. Blackwelder (Duke University), studying the calcium carbonate fraction of the shelf sediments, found that the carbonate content increases markedly in sediments south of Cape Hatteras but decreases locally where the contribution of detrital sediment is high. Onslow Bay, N.C., for example, lacks major Piedmont rivers and has sediments containing an average calcium carbonate content of about 35 percent, whereas in Long Bay and Raleigh Bay the carbonate content is about 20 percent. The principal carbonate constituent on the inner shelf is mollusks shells, both whole and com-

minuted, and on the outer shelf is algal and barnacle debris derived in part from a peripheral algal ridge. I. G. Macintyre (Duke University) found two species of tropical reef corals *Solenastrea hyades* and *Siderastrea siderea*, growing locally on rock ledges.

The fauna of the shelf is largely relict, having been deposited in shallow water during or prior to the Holocene transgression. Most of the shell material is fragmental and worn. Blackened shells, which are common on the shelf, probably became colored by reduction in lagoons and salt marshes at lower sea levels, according to L. J. Doyle (Duke University). R. D. Perkins and S. D. Halsey (both of Duke University) found that the carbonate components are being altered and selectively removed by boring microorganisms.

#### **Glauconite on the southern margin**

C. E. Dill (Duke University) found that the greatest concentrations of glauconite on the North Carolina continental margin occur between depths of 150 and 500 m on the upper continental slope, with very little found on the inner shelf in depths less than 60 m or on the lower slope in depths greater than 1,000 m. X-ray diffraction patterns show that lighter-colored pellets have a higher concentration of mixed-layer silicates. Ethylene glycol solvation shows these layered silicates to be primarily montmorillonite with some illite. There is a marked decrease in the apparent mixed-layer mineral content with increasing darkness or grain color. The patterns show the darkest grains to be almost free of mixed-layer silicates, with sharp peaks that do not vary after ethylene glycol solvation or heating to 200°C for one-half hour. Thus, it seems that in the study area a correlation exists between grain color and the degree of glauconitization of the grains.

#### **Deposition by deep bottom currents**

An examination by C. D. Hollister (WHOI) of precision echograms, seismic-reflection profiles, bottom photographs, and sediment cores from the Labrador Sea and the western North Atlantic revealed sedimentary features, within the upper few kilometers of the sea floor, which were formed through sediment transport and deposition by the Western Boundary undercurrent, a deep southerly flowing current associated with the thermohaline circulation of the Atlantic.

M. E. Field and O. H. Pilkey (both of Duke University) found that sand layers from the Hatteras Outer Ridge-Hatteras Canyon system are abundant, commonly graded, poorly sorted, and contain shallow water shells and unique occurrences of pyrite cementation. In contrast, the sand layers and laminae from the

continental rise immediately to the south of the ridge-canyon system are less abundant, ungraded, better sorted, and finer in grain size than the ridge-canyon sand layers. The results suggest that turbidity current transportation is important only in the canyon vicinity. To the south, laterally flowing bottom currents are primarily responsible for sediment transportation.

#### **Detailed study of an area in the Gulf of Maine**

Geophysical investigations in the Jeffreys Ledge quadrangle, western Gulf of Maine, by R. N. Oldale (USGS), B. E. Tucholke, Elazar Uchupi, C. D. Hollister, and K. E. Prada (WHOI), show that the rocky zone near the coast west of Jeffreys Ledge consists of closely spaced Paleozoic igneous and metamorphic bedrock outcrops and as much as 40 m of sediment in deep depressions cut into the basement by glacial erosion, possibly along preglacial fluvial valleys. Seaward of this rocky zone, the bottom is generally smooth and in some places the sediment cover exceeds 40 m. Preliminary examination of seismic-profiler data suggests that Jeffreys Ledge and possibly the upper part of Stellwagen Bank may represent a submerged, late Pleistocene end moraine with several interlobate angles. The fine-grained sediment landward of these features may in part represent glaciomarine sediments deposited during Holocene submergence or glaciolacustrine sediments deposited in lakes dammed by the moraine.

#### **New England seamount chain**

Seismic and magnetic data collected by Elazar Uchupi, J. D. Phillips, R. D. Ballard and K. E. Prada (WHOI) suggest that the New England seamount chain, a volcanic belt extending from the upper continental rise to the Bermuda Rise, is located along a fracture zone formed along a discontinuity of the sea-floor spreading pattern. The discontinuity probably resulted from a simple transform fault that may have opened progressively along its length or opened at one time as a result of change in spreading direction. This opening of the fault may have begun during the Triassic and continued to the Cretaceous.

#### **Fauna of the northern margin**

An analysis by R. L. Wigley (BCF) of the fauna of the continental margin from New Jersey northward to Canada revealed that the bulk of the fauna was composed of only four taxonomic groups: Crustacea, Annelida, Mollusca, and Echinodermata. More than 90 percent of the total macrobenthos was made up of these four groups. Crustaceans were the most numerous component, annelids second, and mollusks and echinoderms third and fourth, respectively. In



terms of weight, the order of importance was nearly the reverse. Mollusks were the dominant component, echinoderms ranked second, and the annelids and crustaceans third and fourth, respectively.

### GULF OF MEXICO AND CARIBBEAN SEA

Analysis and interpretation of the extensive data collected by the U.S. Geological Survey and U.S. Naval Oceanographic Office (USNOO) from the USNS *Kane* are continuing and have already provided significant new data on the tectonic setting of the Gulf of Mexico, its potential for oil and gas resources, and the distribution of elements in the sediments of the Gulf. Studies in the Gulf and Caribbean have been conducted in cooperation with U.S. Bureau of Commercial Fisheries (Galveston) and U.S. Coast Guard, and jointly with Texas A & M University (TAM) and Louisiana State University (LSU) under research contract. Scientists of University of Texas Marine Institute (UT), Rice University (RU) and Florida State University (FSU) have collaborated on individual studies. Puerto Rico investigations are pursued in cooperation with the Puerto Rico Economic Development Administration.

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

Preliminary interpretation was made of 15,000 miles of seismic reflection profiles from the Gulf of Mexico, which were obtained by the USNS *Kane* during a joint study by the U.S. Geological Survey and the U.S. Naval Oceanographic Office. L. E. Garrison, H. L. Berryhill, Jr., and USNOO personnel have found a very thick sedimentary section in the deeper parts of the Gulf of Mexico basin, abundant large structural features created by salt tectonics, and a trend of probable reefing extending for over 1,000 miles along the southern and eastern carbonate banks of the Gulf. All these features indicate a high potential for the occurrence of oil and gas.

Analyses by emission spectrograph of 1,500 samples collected during the 1969 summer cruise of the USNS *Kane* indicated abnormally high silver content in cores taken in the western part of the Gulf of Mexico abyssal plain. Amounts up to 15 ppm were recorded.

#### Gulf of Mexico trace-element geochemistry

C. W. Holmes reported that 3,300 surface and core samples from the Gulf of Mexico have been analyzed by semiquantitative methods. In the northwestern sector of the Gulf, the highest relative trace-element concentrations generally occur in regions undergoing active sedimentation. However, a region of nondeposition off

Galveston, Tex., is characterized by anomalously high concentrations of zirconium. The zirconium anomalies occur in patches paralleling topographic features on the shelf. The distribution of sediment types, the zirconium concentrations, and the morphology of the shelf suggest that the topographic features are the result of shoreline sedimentation.

The trace-element concentration of the cored sediments in the basin shows an abrupt change with depth below the sediment-water interface. This change, demonstrated most noticeably by a decrease in calcium content and corresponding increase in zirconium and vanadium content, occurs in nearly all the cores. The chemical inflection may represent changes in rates of erosion in the surrounding regions from glacial to postglacial periods and thus may mark the beginning of the Holocene.

#### Texas barrier-island studies

Studies by K. A. Dickinson showed that a layer of sand coarser than the surficial sand underlies Padre Island in the South Bird Island 7.5-minute quadrangle. This layer lies generally at a depth of from 5 to 10 feet but has been eroded in the deeper parts of deflation basins. The degree of mixture of modern sand with sand from this deeper interval determines the distribution of sand size on the surface. The sand on the present-day beach averages about  $2.6 \phi^{48}$  in grain size and the underlying layer about  $2.3 \phi$ . Both layers probably represent mixtures of sand from a southern source ( $2.0 \phi$ ) and from a northern source ( $3.0 \phi$ ). The change with depth indicates that the convergence zone of net longshore drift has shifted southward from its position earlier in the history of the island.

#### Chloride diffusion from Gulf of Mexico salt deposits

F. T. Manheim (USGS) and D. J. Ekstrand (WHOI) found no analytical solution for the problem of calculating the pattern of chloride concentration in interstitial waters from the sea floor to the sediment-salt interface, because of the complicating influence of concurrent sedimentation. To compare the theoretical pattern resulting from diffusion with actual increases in interstitial chlorinity observed in drill cores down to 619 m, they attempted to apply iterative techniques using the computer at the Woods Hole Oceanographic Institution.

Given the general diffusion equation,  $\frac{\delta c}{\delta t} = \frac{D \delta^2 c}{\delta x^2}$ ,

<sup>48</sup>  $\phi$ , A logarithmic transformation of the Wentworth grade scale based on the negative logarithm to the base 2 of the particle diameter. (See "Phi mean particle diameter" in the "Glossary of Geology and Related Sciences", 2d ed., 1960, published by the American Geological Institute.)

where  $c$  is concentration of chloride,  $t$  is time,  $D$  is the coefficient of diffusion, and  $x$  is the distance of the sediment-water interface from the salt, they solved the equation for given rate of sedimentation (increase in  $x$  with time) and other boundary conditions by using finite-difference approximations to the derivatives  $\frac{\delta c}{\delta t}$  and  $\frac{\delta^2 c}{\delta x^2}$ . The Crank Nicholson method of solution failed to converge within a reasonable number of iterations, but the explicit finite-difference method converged encouragingly in three iterations. The calculated chlorinity for a diffusion coefficient of  $4 \times 10^{-6}$  cm<sup>2</sup>/sec and a sedimentation rate of 4 km/150 m.y. is about 23 ‰ at 600 m depth. Actual chlorinity at this depth is over 30 ‰. This discrepancy may be attributable to conservative diffusion rates, movement outward and upward of salt by other than diffusive means, or as yet unknown factors.

#### **Submarine canyon and faults near Puerto Rico**

Previous work by the U.S. Geological Survey and other investigators in a poorly sounded region off Ponce, Puerto Rico, indicated the presence of a submarine canyon (Cuchara Canyon) trending southwesterly from the shelf edge. Further study by L. E. Garrison using new soundings furnished by the U.S. Coast and Geodetic Survey has shown this canyon to be but one head of a canyon system of major proportions. The system is more than 31 km wide at its nearshore end and includes at least four heads, each of which is aligned with an embayment in the Puerto Rican coast. All heads merge downstream into a single canyon which extends nearly 50 km offshore to depths of more than 3,600 m.

Interpretation of reflection seismic profiles from the Muertos shelf south of Puerto Rico shows three important faults or zones of faulting. In the eastern part of the shelf the great southern Puerto Rico fault zone, which is believed to traverse the island from northwest to southeast, continues southeastward across the shelf from Bahia de Jobos. Its vertical displacement appears to be down to the south. In the western part of the shelf, the basin north of Isla Caja de Muertos is a graben with bounding faults trending southwesterly from Isla Berberia to Caja de Muertos on the south and off Punta Cabullon on the north. On the outer part of the central shelf an east-west fault some 25 km in length parallels the shelf edge. Vertical displacement is down to the north and may be as great as 1 km near the middle. The recency of fault movement is attested to by the fact that the shelf surface is marked by a scarp along the trend of each of these faults.

#### **Geology of southern St. John, Virgin Islands**

Field studies by Gilbert Corwin and J. I. Tracey, Jr., in the vicinity of Lameshur Bay on the southern coast of St. John, Virgin Islands, suggest a relation between metamorphism of a thick, water-saturated volcanic succession to keratophyres and spilites and intense deformation that produced a complex of reverse and thrust faults oriented parallel to the axis of the Virgin Islands platform. Dissected stream terraces, salt ponds, and probable fossils at elevations exceeding 20 m provide evidence for continuing tectonic activity that has resulted in significant amounts of post-Pleistocene uplift of the southern coast of St. John. Despite uplift and terrace dissection, little sediment now reaches the bays, but instead is trapped in the salt ponds and alluvial flats behind storm-built beaches and ramparts across the mouths of deeply incised, drowned Pleistocene valleys.

#### **PACIFIC CONTINENTAL MARGIN**

Marine geologic studies along the earthquake-prone Pacific margin continued to focus on (1) geologic hazards that may affect use of coastal areas and (2) evaluation of the mineral-resource potential of Continental Shelf sediments and bedrock. University of Washington (UW), Oregon State University (OSU), University of Southern California (USC), and Scripps Institution of Oceanography (SIO) participated in the work under research contract to the U.S. Geological Survey. Some studies were undertaken in cooperation with the Water Resources Agency of the State of California and the U.S. Atomic Energy Commission. Others were conducted in collaboration with Stanford University (SU), San Francisco Bay Toll Crossing Authority, Bay Conservation and Development Commission, and the U.S. Department of Housing and Urban Development.

#### **Sediments on continental slope off southern Oregon**

Study of sediments from the continental slope off southern Oregon by L. D. Kulm and J. J. Spigai (OSU) provided much data concerning Holocene sedimentation in this area. Large topographic benches at various depths (250 to 500 m, 500 to 750 m, and 1,000 to 1,100 m) are formed by sediment ponding behind anticlinal folds. The accumulation of Holocene fine-grained sediment on the upper slope and its benches is thin and patchy. Sediments on these benches consist mostly of relict sand, or a thin veneer of stiff gray clay of Pleistocene age; sedimentation rates average less than 10 cm/1,000 yr. In contrast, the lower slope is characterized by more rapid accumulation of Holocene olive gray silty clay, with sedimen-

tation rates varying between 15 and 65 cm/1,000 yr. The upper Rogue Canyon also shows little Holocene sediment accumulation, and the sedimentation rates range from 8 to 12 cm/1,000 yr. In the lower Rogue Canyon, however, the Holocene section thickens, which suggests that this portion of the canyon is filling. The pattern of Holocene sedimentation on the continental slope results from several interacting factors. These include (1) a low sediment supply due to trapping in the bays and estuaries, (2) topographic effects, (3) the possible existence of a southerly current winnowing fine sediments, and (4) sediment bypassing on the upper slope.

#### **Underwater observations in Oregon nearshore zone**

H. E. Clifton, R. E. Hunter, and R. L. Phillips made underwater observations using scuba in the high-energy nearshore zone of Oregon. They report a distinct, consistent zonation of sedimentary structures. Immediately offshore from the beach, large-scale bottom irregularity exists which forms large- to intermediate-scale seaward-dipping crossbedding. In the surf zone the bedform is planar, and internal structure produced is parallel lamination. Seaward from the breaker line, in the zone of wave buildup, are large lunate megaripples, which form large- to intermediate-scale landward-dipping crossbedding. Seaward from the megaripples, beyond the zone of wave buildup, are small-scale asymmetric ripples; internal structure produced in this zone consists of subparallel lamination and landward-dipping ripple lamination. Structures in the surf zone and seaward are explainable in terms of flow regime. The flow regime increases shoreward owing to increases in orbital velocity of shoaling waves combined with the shoreward decrease in water depth. The structure at the base of the beach may be more complex in origin but also can in part be explained in terms of flow regime.

#### **Platinum on northern California Continental Shelf**

The platinum content of three fine-grained sand samples, one each from three areas known to be anomalously rich in gold offshore from the Klamath Mountains, Calif., was investigated by G. W. Moore (USGS) and E. A. Silver (SIO). In an attempt to obtain statistically meaningful results for the sand, which has an average grain size of 0.12 mm, the heavy minerals in 10-kg samples were concentrated to assay-sized fractions in the heavy liquid thallium mullonate-formate, which has a specific gravity of 4.6. Despite the relatively large size of the samples before concentration, two of them contained only single grains of platinum and one none at all. These results place lim-

its on the platinum grade but do not permit it to be assigned exact values. Comparison with the gold content of the same samples suggests that the platinum content, roughly 10 ppb, is an order of magnitude less. The platinum grade is presumably lower than this outside of the gold anomalies, and it may be greater at the base of the sand layer, which is known from subbottom acoustic profiles to be less than 10 m thick.

#### **Dolomite on northern California continental margin**

Dolomitic concretions were the dominant rock found by E. A. Silver (SIO) in eight widely separated dredge hauls ranging in depth from 450 to 1,050 m at the top of the continental slope off northernmost California. These rocks contain Foraminifera of probable Pliocene age and lie along the axes of anticlines. The common occurrence of such rock on the northern California continental margin suggests that the rock may be widespread in similar geologic settings. The present environment is characterized by a slow rate of deposition, as indicated by sediment lapping out on the flanks of the anticlines, intensive boring of the dolomite rock, and the presence of glauconitic sand at one locality.

#### **San Francisco Bay, Calif.**

A topographic map of the subsediment bedrock surface of central San Francisco Bay, Calif., was drawn from closely spaced, continuous acoustic-profile lines by P. R. Carlson and D. S. McCulloch. The topography defines a ridge that runs north from the northeast edge of the San Francisco Peninsula to the Tiburon Peninsula; Alcatraz and Angel Islands lie on the eastern flank of the ridge. Paleodrainage lines drawn on the bedrock surface suggest that the ridge was a drainage divide. In turn, this suggests that the large discharge of the Sacramento-San Joaquin Rivers, which now flows out through Golden Gate, must have followed some other route to the Pacific Ocean.

Transbay acoustic profiles also define the geometry of the Bay sediments. Comparison of these profiles with data from Bay Toll Crossing Authority boreholes demonstrate that reflectors within the sedimentary layers can be correlated with lithologic units recognized in the boreholes.

Related results bearing on environmental problems in San Francisco Bay are reported in the section "Estuarine and Coastal Hydrology" (p. A105-A107).

#### **Cooperative studies in Monterey Bay, Calif.**

Joint studies with the California Water Resources Agency in Monterey Bay, Calif., started in 1969 with the cruise of the RV *Polaris*. Over 800 miles of continu-

ous, seismic-reflection profiles were obtained. Magnetic, bathymetric, high-resolution seismic, and deep-penetration seismic data were collected simultaneously. Preliminary interpretations of the high-resolution seismic profiles by H. G. Greene (USGS) and by J. S. Nelson and R. S. Ford (State of California, Water Resources Agency) indicated that lithologic units containing fresh-water aquifers onshore can be traced offshore. The aquifers appear to be faulted or bent upward to the ocean bottom rather than continuing on to crop out in Monterey Canyon. Initial examination of the deep-penetration seismic profiles by Greene showed that, in the southeastern portion of Monterey Bay, the Monterey Formation of Miocene age is gently folded with several extensive anticlines and synclines. In the northern portion of the bay the Purisima Formation of Pliocene age is little deformed and has a gently dipping homoclinal structure. Several buried channels related to the Monterey Submarine Canyon are present in this area. Profiles across Monterey Canyon show many slump blocks in various degrees of development, and it seems most likely that the upper canyon walls and edges within the bay have been shaped by mass wasting. Only a thin veneer of recent sediment overlies the older Tertiary rocks of Monterey Bay.

#### **Continental borderland of southern California**

A long-planned investigation to determine the geologic framework and depositional history of the southern California borderland from Point Conception to the Mexican border began this year. The program is designed to provide geologic and related information needed to define areas of potential hazard to human life and property in the coastal area and areas of economic resource potential in the offshore area.

In the Santa Barbara Channel area about 425 miles of high-resolution seismic and deep-penetration seismic surveying was performed between Point Conception and Point Mugu. Interpretation of these and other seismic records, as well as records furnished from onshore and offshore petroleum exploration and development, provided much of the data published in Professional Paper 679. In this report, the geologic framework and petroleum development of the Santa Barbara Channel were discussed by J. G. Vedder, H. C. Wagner, J. E. Schoellhamer, (r2536) and others.

#### **Climatic changes recorded in southern California basins**

D. S. Gorsline (USC) reported that basin sedimentation patterns during the past 12,000 years have

shown similar properties in three different basins of the continental borderland off southern California. The patterns reflect periodic climatic fluctuations that appear to be similar to those noted in other areas of the world ocean but are recorded in much more detail here than in the thinner deep sea accumulations. Therefore, an easily applied tool for describing late Pleistocene climatic cycles may be available in the record of carbonate sedimentation in these basins.

#### **Pleistocene deposits along southern Oregon coast**

The coastal deposits and landforms of northern Curry County, as interpreted by R. J. Janda, record five middle and late Pleistocene eustatically controlled marine transgressive-regressive cycles. Sediments deposited during the three oldest cycles bear latasolic weathering profiles, whereas sediments deposited during the two youngest cycles bear podzolic weathering profiles. Locally podzolic profiles are superimposed on older latasolic profiles. Possibly the younger profiles developed under cooler and (or) drier conditions than did the older profiles.

Study by W. O. Addicott of new mollusk collections from the Port Orford Formation of Baldwin (1945) indicated that the formation is probably of early Pleistocene age rather than middle to late Pliocene as was suggested by previous authors. Therefore, the rather complex, local sea-level history recorded by the Port Orford Formation may result from eustatic events as well as from local tectonism.

#### **ALASKAN CONTINENTAL MARGIN**

Several notable accomplishments were achieved in the study of the marine resources of the nation's largest Continental Shelf area. The joint U.S. Geological Survey-U.S. Coast Guard study in the Chukchi Sea from the USCG buoy tender *Storis*, showed the continuation of geologic framework of the Brooks Range and adjacent Mesozoic basin beneath the Chukchi Sea, and broadly delineated a Tertiary sedimentary basin. Further study of the southern Bering Shelf disclosed the existence of diapiric structures and major faults, and added to knowledge of liquid fuel potential. Analyses of thousands of miles of profiles, and of a large collection of bottom samples, has permitted a preliminary assessment of the structural, glacial and depositional history of the northern Bering Sea. Studies were conducted jointly with the University of Washington (UW) and the University of Alaska (UA) under research contract to the Geological Survey, and in cooperation with U.S. Coast and Geodetic Survey, U.S. Coast Guard (USCG),

U.S. Navy Undersea Research and Development Center, and U.S. Bureau of Mines.

#### **Turbid-layer sediment transport in southern Alaska**

Studies by F. F. Wright (UA) resulted in the recognition of a characteristic periglacial marine sediment that occurs on the Continental Shelf and in fiords fed either by active glaciers or by streams that carry a great deal of glacial melt water. The sediments consist of mixtures of silt and clay; some contain only small amounts of coarse erratic debris and low concentrations of all organic constituents. Extremely high rates of accumulation are suggested. These sediments are dispersed in fiords by means of turbid-layer transport. Turbid layers are sediment-laden currents at the top of or within the water column. They are most common during the summer and autumn when there is high runoff and well-developed thermohaline stratification in the fiords.

#### **Heavy-metal concentrations along the Gulf of Alaska coast**

Beach sediments along a 300-mile stretch of the Gulf of Alaska coast were sampled for gold analysis. Field observations by Erk Reimnitz indicate that heavy-metal concentrations in the beach deposits extend westward to the Copper River delta, much farther than previously reported. Observations and a literature survey suggest that heavy-metal concentrations in beaches are ephemeral. Therefore, certain areas immediately seaward of modern and older beaches may be heavy-metal reservoirs. The ephemeral nature of heavy-metal accumulations in beaches also suggests that the feasibility of trapping and further concentrating these materials in transit should be tested.

#### **Underthrusting in the Aleutian Trench**

R. E. von Huene reported that a series of seismic transects suggested underthrusting in the Aleutian Trench off Kodiak and Amchitka Islands. Here, a complex pattern of reflections may be highly deformed sediments or large slumps. High-powered instruments with greater resolution than generally attained are required to delineate folded structure and give a record that clearly shows the acoustic basement in this area.

#### **Structure of southeastern Bering Sea**

Six diapiric folds have recently been located in the southeast corner of the Bering Sea by seismic-reflection profiling, D. W. Scholl reports. The diapirs are beneath Umnak Plateau, a wedge-shaped platform at a depth near 2,000 m just north of the Aleutian Ridge. The intrusive folds occur in Neogene strata that are

as much as 3,000 m thick. Intrusion of shale or possibly igneous bodies is thought to have formed the folds in late Tertiary time.

Recent geophysical work has also outlined a broad trough extending southwestward from the Yukon delta. This trough is filled with as much as 2,000 m of strata of Cenozoic age resting unconformably on broadly folded strata probably of Mesozoic age. This sediment-filled trough is thought to mark the seaward trace of the Kaltag fault, a major strike-slip fracture in western Alaska.

#### **Geology of the northern Bering Sea**

Thousands of miles of continuous seismic and bathymetric profiles, about 1,000 large bottom grab samples, and over 100 box cores have been collected in the northern Bering Sea by C. H. Nelson, D. M. Hopkins, and H. G. Greene in cooperation with the University of Washington and the U.S. Coast and Geodetic Survey. These investigations have revealed the general structural, glacial, and depositional history of the area. A large Tertiary basin underlies the region. Faults and linear structures near the basin margin on the south side of Seward Peninsula have caused a marked linear topography and have localized major sea valleys that became drainage pathways during periods of lowered sea level.

During emergence of the region, continental glaciers extended more than 150 km of Chukotka, Siberia, toward the center of the basin. Different advances and retreats of this major glaciation left a series of morainal ridges that are buried by younger sediments in the central areas of the northern Bering Sea but are emergent as linear gravel bars south of the Bering Straits and north of St. Lawrence Island. These Siberian gravels are distinguished by their content of acid volcanic rocks, amphiboles and native copper flakes. Local valley glaciers extended 5 to 10 km off the southern Seward Peninsula coast and scraped placer material en masse to offshore locations. Transgressions and regressions of the shoreline, as well as stream erosion, has reworked the drift and left a relict gravel mantle. This gravel is highly auriferous in the Nome nearshore region and may constitute a minable resource. Numerous beach ridge remnants (at depths of about 36, 55, 70, 80, and 115 feet) remain exposed on the sea floor and are identified by their linear topographic scarps and ridges, their subsurface expression as constructional lenses of sediment, their clean, well-sorted, well-rounded, oxidized coarse sands and gravels, and their occasional shell beds, heavy-mineral concentrations, and higher quantities of quartz pebbles.

The modern sea floor is being modified by current

scour, which locally, as in the Bering Straits and northwest of St. Lawrence Island, exposes hummocky topography of the underlying glacial debris. Beyond the lee side of the scour channels, slackening of currents has resulted in the buildup of depositional wedges of sediment to form shoals such as the Cape Prince of Wales Shoal and the Northeast Cape Shoal. Except for the Chukotka morainal ridges, nearshore areas, and straits regions, where current scour preserves the relict glacial gravels at the sea floor surface, most of the Bering Sea bottom has a thin blanket of transgressive, fine-grained marine sands. These sands contain particulate gold (fine sand size or smaller) throughout the region but are not of economic significance.

Deposition from the modern Yukon River occurs in a narrow belt about 60 km wide off the delta and throughout the Norton Sound area where sediments are ponded by the modern current regime. The modern Yukon deposits are identified by their high silt content and interlaminated beds of fine sand and clayey silt. Ancient, buried depositional wedges of Yukon sediment appear to have extended far across the northern Bering Sea and probably account for the smooth topography that is found within a radius of about 200 km from the modern delta.

Studies by Dr. Kolla Venkatarathnam (UW) identified some seven suites of heavy minerals in the bottom sediments of northern Bering Sea. The seven suites can be related to different source areas about the Alaskan and Siberian shores of northern Bering Sea; their distribution suggests that the bottom sediments are mostly relict, having been moved by waves or longshore currents when sea level was lower than at present.

#### **Search for placer deposits off Goodnews Bay**

Investigations have been started by A. R. Tagg and coworkers into the possibility of the presence of economic platinum placers offshore from Goodnews Bay, which is a large platinum producer. These investigations have included beach and offshore sediment sampling, assays of the samples for platinum and gold, and high-resolution seismic profiling. Only a few of the offshore samples and one of the beach samples have shown minor amounts of gold, although nearly all previous samples taken by the U.S. Bureau of Mines in the same area contained some gold. The platinum assays have not yet been completed.

A bathymetric map covering an area as much as 20 miles offshore is being constructed from data of the U.S. Coast and Geodetic Survey. Notable among the offshore features revealed by this map are several long

straight sandbars measuring 1 mile by more than 20 miles and with relief of 10 to 90 feet in less than one-half mile. The origin of these bars is uncertain. However, sampling of one bar has demonstrated the sandy character of the surface sediment, and the features may be sandbars associated with the Kuskokwim River, even though the river mouth is nearly 40 miles to the north. They may have formed during a lower stand of sea level. A glacial origin seems questionable if the character of the one surface sample is typical.

#### **Joint U.S. Geological Survey—U.S. Coast Guard Chukchi Sea study**

The U.S. Geological Survey, in collaboration with the U.S. Coast Guard, conducted a cruise to study the geology of the Chukchi Sea. The work was originally planned for the Beaufort Sea, but was shifted to the Chukchi Sea because the most difficult ice conditions in 15 years prevented work in the Beaufort Sea. The joint effort employed the Geological Survey's high-power 160,000-joule sparker system, a new high-resolution 1,000-joule sparker system, a proton precession magnetometer, and precision depth recorders; the Coast Guard conducted a sonobuoy experiment to obtain wide-angle reflection and refraction data. Exceptionally accurate position control was obtained by a combination of navigation satellite and loran-C navigation systems supplied by the Coast Guard. The work was conducted on the reinforced USCG buoy tender *Storis*. Although a search and rescue mission and damage sustained by *Storis* in heavy pack ice off Franklin Point limited the Arctic scientific work to 8 of the 21 days originally planned, 1,350 nautical miles of track were made in the Chukchi Sea at an average speed of 6.9 knots.

Geologists on the cruise were Arthur Grantz, principal scientist, Erk Reimnitz and S. C. Wolf (USGS), and L. R. Breslau, Ensign T. C. Johnson, and C. C. Bates (USCG). Grantz reported that the roots of the Brooks Range and the frontal fault system that separates the Brooks Range rocks from the oil- and coal-bearing rocks of the Colville geosyncline of the North Slope were traced from Cape Lisburne northwestward to the north side of the Herald Shoal, a distance of 175 nautical miles. Folds in the Cretaceous rocks of the southern part of the Colville geosyncline of western Alaska were shown to extend offshore only part way to Herald Shoal; in much of the Chukchi Sea, these rocks are flat lying to gently folded near their contact with the seaward extension of the frontal fault system of the Brooks Range. The southern Chukchi Sea was found to be underlain by a thick and extensive body of folded sedimentary rocks, probably of Tertiary age.

### OCEANIC AND INTERNATIONAL STUDIES

Diversified investigations of the marine geology of the deep-ocean floor and of small ocean basins, although a small part of the U.S. Geological Survey's program, were continued as contributing to understanding of the formation of and relation between ocean basins and continental masses.

#### Effects of deep-sea benthos on sediment

C. D. Hollister (WHOI) found that the majority of bottom photographs taken on the deep sea floor show numerous indistinct mounds and depressions, as well as occasional tracks or fecal coils produced by benthic animals. An examination of over 100,000 photographs taken in water depths greater than 3,000 m has revealed many organisms producing their traces. Most walking trails composed of discrete "footprints" are produced by holothurians. Large tractor-tread trails are probably made by mud-eating asteroids, and many of the grooves and furrows are echinoid traces. Ropelike fecal coils are produced by holothurians, and planispiral feces are produced by hemichordates.

#### Geochemistry of interstitial waters of pelagic sediments

F. T. Manheim (USGS), F. L. Sayles (WHOI), and K. M. Chan (California State College at Long Beach) found that major compositional effects due to diagenetic interaction of sediments and pore waters include loss of magnesium, sulfate, slight gain in potassium in near-surface sediments, and preferential enrichment of certain minor constituents such as lithium. In clayey clastic sediments near the continents or otherwise showing terrigenous affinities, drastic shifts in ionic ratios are found, leading to marked depletion in magnesium, potassium, calcium, and sulfate (lowering total salinity to as little as 31 ‰ without materially changing chlorine) in some instances and to considerable enrichment in calcium (and minor constituents such as strontium, lithium, and barium) in others.

#### Geology of the Black Sea

D. A. Ross, Elazar Uchupi, C. O. Bowin and K. E. Prada (all of WHOI) collected echo-sounding profiles during an expedition to the Black Sea. These profiles, supplemented by published information, indicate that the Continental Shelf has its greatest development south of Odessa where it is over 200 km in width. Elsewhere the shelf is less than 20 km wide. The continental slopes are about 1,800 meters high, and are deeply entrenched by submarine canyons, except for the seaward slope, off the Danube River, which is only about 1,000 meters high and is relatively smooth. Seaward, the Danube fan has buried most of

this slope and has prograded across the abyssal plain that occupies the central part of the Black Sea.

Continuous seismic profiles across the continental slopes generally show extensions of land structure. This is especially so along the east coast where ridges possibly related to the Caucasus Mountains trend across the shelf and slope. Some diapirs were observed in the northeast part of the Black Sea near the Kerch Peninsula. Records from the abyssal plain generally showed it to be featureless, except near the continental slopes where there was considerable evidence of faulting and slumping.

#### Interstitial water of Black Sea sediments

F. T. Manheim found that interstitial salinities in surface muds of the Black Sea are similar to those in overlying bottom waters (21–22 ‰), but generally decrease with depth, as has been reported by Soviet workers. The general decrease has been attributed to fresher bottom waters during earlier (Pleistocene) stages of the Black Sea.

Record low salinities of 6 ‰ were obtained in interstitial waters from the northwest part of the deep Black Sea basin, about 150 km west of Sevastopol (Crimea), whereas on approaching the Bosphorus (outlet to the Mediterranean Sea) interstitial salinities increased rather than decreased with depth.

Mapping of interstitial-salinity distribution at depths of 2 and 5 m below the sediment-water interface has shown a markedly fresher character in pore waters adjacent to the Danube delta and the Irmak delta (largest Turkish river discharging into the Black Sea). This suggests that fresh waters from the river systems influence sediments considerably beyond the geographic limits of fresh water influence in the Black Sea proper.

#### Participation in JOIDES Deep Sea Drilling Project

J. D. Bukry participated in leg 6 of the JOIDES (Joint Oceanographic Institutions Deep Earth Sampling Committee) Deep Sea Drilling Project aboard the *Glomar Challenger*, managed by Scripps Institution of Oceanography and sponsored by the National Science Foundation. Shipboard work on fossil nannoplankton from cores recovered during the cruise to the northwestern Pacific helped confirm the worldwide similarity of oceanic nannoplankton assemblages. The stratigraphic zonation of Cenozoic oceanic sediment determined for cores from the South Atlantic was recognized in the northwestern Pacific because assemblages of identical species were present. Furthermore, the oldest nannoplankton assemblage (Late Jurassic) known from the Pacific was recovered dur-



ing this cruise at the Shatsky Plateau (32°24' N., 156°36' E.), and it corresponded, in species composition, to the oldest marine sediment recovered from the Atlantic. The coring sites of both of these oldest rocks in the Atlantic and Pacific are located near the margins of the ocean basins, far from the oceanic ridges where active spreading is occurring, and thus Jurassic sediment may well be the oldest that will ever be recovered from the present oceans.

#### **Substructure of Hawaiian volcanoes**

Evidence from 53 oceanographic stations yielding ocean-bottom photographs and dredge hauls near the island of Hawaii have been compiled by J. G. Moore and R. S. Fiske in a study of the submerged part of the volcanic structure. The distribution of rock types on the submerged flanks of the volcano indicate that three major rock units correspond to different levels of the volcanoes depending on the site of eruption: (1) pillow lavas and pillow fragments are dominant below sea level and are erupted from deep-water vents; (2) hyaloclastite rocks (vitric explosion debris, littoral cone ash, and flow-foot breccias) mantle the pillowed base of the volcano and are erupted from shallow-water vents, from subaerial vents in water-soaked ground, or are produced where subaerial lava flows cross the shoreline; and (3) thin subaerial lava flows make up the visible, subaerial shield volcano, are built atop the clastic layer, and are erupted from subaerial vents. This threefold structure is similar to the table mountains of Iceland that are built by eruption beneath glacial ice.

Large-scale slumping in the clastic layer may modify the submarine slopes of the volcanoes as well as produce faulting and downslope movement of parts of the overlying shield volcano. The slope change produced where the gentler shield meets the steeper pillowed pile can be recognized beneath sea level in the older volcanoes where it has been submerged by regional subsidence.

#### **Deep oceanic crustal rocks**

A 2,000-km segment of the Mid-Indian Ocean Ridge was studied by C. G. Engel and R. L. Fisher. The segment is mantled by basalts of uniform composition; they are low-potassium, olivine-bearing oceanic tholeiites. Garnet-bearing lherzolite, anorthosite, and gabbros are exposed in the deep cross fractures, and lherzolite is the bedrock at the center of the ridge.

A. E. J. Engel reports that oceanic crust away from ridges and rises shows subtle systematic changes in composition with increasing age but contains no known or readily inferred concentrations of minerals

of economic value in the upper one-half or two-thirds (3 to 4 km) of the crust seaward from the continental slopes. There is a strong possibility, however, that stratiform sheets exist within the basal layer of the oceanic crust. These sheets may include layers enriched in titanium, iron, chromium, nickel, arsenic, copper, and other elements.

#### **APPRAISAL OF MARINE MINERAL RESOURCES**

The first edition of the preliminary maps of world subsea mineral resources by V. E. McKelvey and F. H. Wang (r2575) represents a first attempt to summarize the geological, geophysical and geochemical data related to marine mineral resources and to outline the location, extent, and potential of these minerals throughout the world oceans. It describes subsea geologic features and provinces, reviews seabed resources including petroleum, potash and other saline minerals, sulfur, phosphorite, manganese nodules, and other metalliferous deposits, and indicates the environments in which these resources are likely to occur.

A revised edition of a report on mineral resources of the sea, prepared by Wang in 1969<sup>49</sup>, was used by the United Nations Economic and Social Council and the United Nations Seabed Committee to study long-term programs of ocean exploration and problems concerning peaceful uses of the seabed beyond the limits of national jurisdiction. A more comprehensive version of this report is being published in four languages in book format by the United Nations.

#### **ESTUARINE AND COASTAL HYDROLOGY**

##### **ESTUARINE SALINITY AND DISPERSION**

The salinity of an estuary is a highly variable quality that is responsive to the rate of fresh-water inflow to the estuary, to ocean-induced tides, to transient meteorological tides, and to the dispersive characteristics of the estuary. Several investigators reported on the effects of fresh-water inflow on estuarine salinity and on theoretical and empirical studies of estuarine dispersion.

D. H. Peterson, P. R. Carlson, and L. E. Schemel found that the inflow of the Sacramento River in California affects the advective transport of dissolved constituents from the southern part of San Francisco Bay. They found an increase of dissolved constituents in the southern part of the bay during the summer months when fresh-water inflow is low. Then, during the winter months when the inflow is high from the Sacramento River, the major source of fresh-water inflow to the bay, the concentration of dissolved constituents de-

<sup>49</sup> United Nations Economic and Social Council, 1969, Mineral resources of the sea: 47th session agenda item 12(a), June 1969, 124 p.

creases as the constituents are diluted and transported out of the bay. In another study of the bay, Peterson, T. J. Conomos, and W. W. Broenkow reported that the Sacramento River is also the dominant source of dissolved silica for the bay. They suggested that a one-dimensional model of advection, dispersion and photo-synthetic utilization of dissolved silica should be a feasible tool for predicting phytoplankton growth. Silica is utilized by diatoms, which make up the largest group of phytoplankton in the bay.

A study by W. E. Webb of the extent of brackish water in Maryland estuaries indicated that the range of salt-water intrusion into several estuaries can be very large. A tabulation of the range of the fresh-water volume found at low tide in the estuaries indicated that the volume of water with a dissolved-solids concentration of less than 1,000 mg/l can range from about  $3.3 \times 10^{10}$  to  $2.0 \times 10^{11}$  gallons at low tide in the Potomac River estuary. The volume of fresh water at low tide in the Patuxent River estuary ranges from  $3.7 \times 10^8$  to  $8.2 \times 10^9$  gallons.

In a statistical analysis of specific-conductance data from the Delaware River estuary water-quality monitoring system, R. W. Paulson correlated the high-tide position of the 250-mg/l isochlor with the flow of the Delaware River at Trenton, N.J., the largest tributary to the estuary. It was found that the isochlor occasionally advanced to the Pier 11, Philadelphia, Pa., monitoring site when the daily mean flow of the river at Trenton was less than 3,500 cfs. A daily mean flow of 8,500 cfs at Trenton kept the isochlor seaward of the Chester, Pa., monitoring site. The analysis indicated that only under extreme conditions of high fresh-water inflow can the isochlor be expected to remain seaward of the Reedy Island, Del., monitoring site at high tide.

A recently completed study of the north and south arms of the Santee River estuary, South Carolina, by T. R. Cummings related fresh-water inflow and tidal conditions to the chemical and physical characteristics of the water. Under conditions of a 500-cfs inflow, the average rate of inflow, both arms of the estuary were moderately to highly stratified. Above river-mile 14 on both arms, water is of excellent quality for most domestic, industrial, and agricultural uses, and for the propagation of fish and aquatic life. At river-mile 12, maximum specific-conductance values are 10,000 to 15,000  $\mu\text{mhos}$ ; however, at river-mile 5, maximum specific-conductance values are 40,000 to 50,000  $\mu\text{mhos}$  on both arms.

The effects of the dry season of 1969 on the biota of the Shark River estuary in the Everglades National Park, Fla., were reported by B. F. McPherson. As fresh-

water inflow to the estuary dropped off during the dry season, brackish-water animals extended their range well up the estuary. The headwaters then became a rich feeding ground for large predatory fish and birds as fresh-water forms became concentrated in the headwaters during the season. Fish kills occurred in some creeks at this time as dissolved oxygen dropped below 2 mg/l. The death and oxidation of large amounts of submerged vegetation, which were presumably caused by salinities in excess of 3,000 mg/l, caused the low dissolved-oxygen concentration.

The dispersion characteristics of an estuary must be known before the fate of a pollutant injected into the estuary can be predicted. H. B. Fischer devised a numerical technique to predict the dispersion of pollution in a branching one-dimensional estuary. The technique, which was verified by two field experiments in Bolinas Lagoon, Calif., can be applied to a wide variety of tidal lagoons and deltas. The predictive technique requires no rate coefficients that would have to be obtained by field measurements in the prototype estuary. In a more empirical study, E. F. Hubbard, W. G. Stamper, and N. M. Jackson determined the dispersive and assimilative characteristics of a reach of the Northeast Cape Fear estuary near Wilmington, N.C. Rhodamine WT dye was continuously released for a period of two tidal cycles, 24.8 hours, and the concentration dye was monitored at several locations for 17 days. These data indicated, for example, that at average intervals of 10 years the inflow is so low that 100 days are required for a pollutant to travel the 6.4 miles from the point of waste release to the mouth of the river. Under these conditions, it is expected that concentrations 1,000 feet downstream from the point of waste discharge will build to an average daily maximum of about 0.025 mg/l for each 100 pounds of pollutant injected per day.

#### ESTUARINE WATER QUALITY

A continuously recording water-quality monitoring station, which was partially supported by International Hydrologic Decade funds, was dismantled recently, after 6 years of operation on the Patuxent River estuary in Maryland. During the 6-year period the amount of domestic sewage released to the upper reaches of the estuary increased, resulting in increased phytoplankton growth at the monitoring station. R. L. Cory and J. W. Nauman reported that dissolved-oxygen concentration levels at the site have accurately documented the progression of eutrophication.

Cory and Nauman also reported on a study of the effects of effluents from a large paper pulp mill on the epifauna in the Newport River estuary in Georgia.

After a preliminary analysis of data from four test panel stations, which were reestablished in the estuary after an interim of 1 year, a large increase in epifaunal production was noted at stations downstream from the mill. There, epifaunal production from June through August 1969 was as much as five times greater than observed during the same period of the years 1966 and 1967. The analysis also showed that practically the same fauna was found in the estuary, but that the fauna was significantly shifted downstream. The shift was attributed to an increase of fresh-water inflow to the estuary and to the pulp mill effluent.

## **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 natural 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 to realize a fair market value from the sale of leases and to obtain satisfactory royalties on mineral production; and (5) cooperation with other agencies on mineral-land needs and problems.

### **MAPPING AND EVALUATION OF MINERAL LANDS**

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

### **Classified land**

As a result of U.S. Geological Survey investigations, over 50 million acres 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 U.S. Government, in disposals of public land, the title to such energy resources as coal, oil, gas, oil shale, and bitumens, and such fertilizer and industrial minerals as phosphate, potash, sodium, and sulfur. These reserved minerals on public lands are subject to development by private industry under the provisions of the Mineral Leasing Act of 1920. All minerals in acquired lands and on the Outer Continental Shelf are subject to development under comparable acts.

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

### **Coal resources in the Powder River Basin of Wyoming**

Geologic studies by the U.S. Geological Survey in the Wyoming portion of the Powder River Basin in 1908-11 and 1923-24 revealed large resources of sub-bituminous coal. In response to the increasing number of requests from industry for more land for coal prospecting and leasing under the provisions of the Mineral Leasing Act, the eastern Powder River Basin coal outcrop south of Gillette, Wyo., was remapped during fiscal years 1967-70. As a result of this work, an additional 9,680 acres containing about 1,030 million tons of coal were discovered. The coal has an average thickness of 60 feet and is under less than 150 feet of overburden. It is estimated that enough additional coal has been discovered by this remapping to supply the energy needs of one million persons for 200 years at the present rate of consumption.

### **Producing oil and gas structures**

During fiscal year 1970, almost 300,000 acres of Federal oil and gas lands were determined to be in undefined "known geologic structures of an oil and gas field." An additional 100,000 acres were determined to be in defined structures. The largest such defined structure was the Cotton Draw field, in New Mexico, which encompasses more than 11,000 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 1970 the review program was carried on in 10 river basins in the Western States. The result after needed additions and eliminations was a net reduction of about 80,000 acres 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 1970, fieldwork was completed on damsite surveys in Montana and Oregon, and maps of several dam and reservoir sites in Alaska 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 com-

pliance with regulations and approved methods, and (4) verification of production and the collection of royalties. (See table 1.)

For the past 5 years, oil and gas production in the Outer Continental Shelf has increased at an average annual rate of more than six times the onshore rate.

### Royalty accounting data

In recent years, there has been a large increase in the amount of royalty accounting data to be processed by the U. S. Geological Survey. A number of major oil companies are now providing computerized input tapes from their own accounting systems in lieu of specially prepared typewritten forms. These tapes can be fed directly into the Survey's computerized accounting system. The processing of royalty accounting is thus speeded and errors reduced.

### COOPERATION WITH OTHER 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 on the mineral character of specific tracts of Federal lands under their supervision which are proposed for sale or exchange. More than 5,000 such reports were made during fiscal year 1970, and nearly 10,500 reports were made on Federal oil and gas lands proposed for permit or lease. Almost 120 special mineral appraisals were made for the U.S. Bureau of Indian Affairs on Choctaw-Chickasaw lands in Oklahoma.

### 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 detonation, which created a large underground cavity, was intended to fracture low permeable gas formations and thus revive gas pressures. In March 1970, a test hole 175 feet from the central drill hole was

TABLE 1.—*Mineral production, value, and royalties for fiscal year 1970<sup>1</sup>*

Lands	Oil (barrels)	Gas (thousand cubic feet)	Gas liquids (gallons)	Other <sup>2</sup> (tons)	Value (dollars)	Royalty (dollars)
Public.....	209, 000, 000	920, 000, 000	450, 000, 000	26, 318, 000	\$891, 413, 000	\$96, 665, 000
Acquired.....	11, 348, 000	27, 400, 000	400, 000	282, 000	82, 080, 000	6, 702, 000
Indian.....	43, 443, 000	92, 810, 000	61, 215, 000	10, 682, 000	146, 255, 000	18, 352, 000
Military.....	1, 000, 000	30, 000, 000	30, 000, 000	-----	8, 000, 000	1, 200, 000
Outer Continental Shelf.....	308, 841, 000	2, 190, 575, 000	637, 000, 000	1, 353, 000	1, 520, 176, 000	251, 796, 000
Naval Petroleum Reserve No 2.....	2, 800, 000	4, 600, 000	11, 100, 000	-----	10, 720, 000	1, 429, 000
Total.....	576, 432, 000	3, 265, 385, 000	1, 189, 715, 000	38, 635, 000	2, 658, 644, 000	376, 144, 000

<sup>1</sup> Estimated, in part.

<sup>2</sup> All minerals except petroleum products; includes coal, potassium, sodium, and so forth.

reentered and cleaned out to a depth of 6,000 feet. At this depth, the hole was turned and drilled to intersect the cavity at approximately 8,000 feet. During the next fiscal year, after the cavity has been

entered, tests will be made to determine whether commercial quantities of gas can be produced, and whether similar detonations will help revive other old gas fields.



# GEOLOGIC AND HYDROLOGIC PRINCIPLES, PROCESSES, AND TECHNIQUES

## EXPERIMENTAL GEOPHYSICS

### CRUST AND MANTLE STUDIES

#### Seismic-refraction measurements in the Columbia Plateau

In August 1969 the Dominion Observatory of Canada detonated a series of 19 chemical explosions in Greenbush Lake, British Columbia, under Project EDZOE. These explosions (up to 17 tons of explosives per shot) were recorded by several United States and Canadian research organizations along profiles radiating from the lake. D. P. Hill analyzed the traveltime data along a profile extending directly south from the shotpoint across the Columbia Plateau and into eastern Oregon. The data were recorded by one U.S. Geological Survey and two California Institute of Technology seismic recording units. Arrival times of P waves emerging through the crust beneath the Columbia Plateau were found to be as much as 1.5 seconds early with respect to average arrival times of P waves both north and south of the Columbia Plateau. These early arrival times suggest that the crust under the Columbia Plateau is both thinner (by 10 to 15 km) and has a higher average P-wave velocity than the crust under adjacent areas. These represent the first crustal seismic-refraction measurements obtained in the Columbia Plateau, one of the largest basaltic flood-plain provinces in the world.

#### Keweenawan tectonics in the midcontinent region

Aeromagnetic surveys were used to map the sub-surface extent of the great belt of Keweenawan mafic rocks that crop out around Lake Superior and extend under Paleozoic and younger rocks as far as central Kansas, giving rise to the well-known midcontinent gravity high. The intricate magnetic pattern associated with the mafic rocks indicates that they form a long semicontinuous block averaging 40 miles in width and consisting mainly of a sequence of layered flows. The linearity of the outer anomalies indicates that the flows have been tilted up along the margins. A smoother magnetic pattern occurs over the associated clastic rocks which form basins along both sides of the block as well as grabens and a series of axial basins on the block's upper surface. Well-defined outliers and truncation of some of the outermost

flows suggest that the present boundaries of the block are postdepositional structural features. The basins and edges of the block appear to have controlled later, largely vertical movement in the overlying Paleozoic and younger sedimentary cover.

Models calculated from coincident magnetic and detailed gravity profiles show that the block is steep sided and as much as several miles thick. The flows have a strong remanent magnetization which accounts for the persistent lows along the western edge of the block. A group of flows of nearly opposite polarity near the base of the sequence may be the cause of an unusual magnetic low on the eastern side of the block north of Des Moines, Iowa.

E. R. King and Isidore Zietz,<sup>50</sup> in their comprehensive study of this feature, conclude that this belt of mafic rocks is a rift of Keweenawan age cutting the east-west-trending fabric of the older Precambrian terrane.

#### Crustal inhomogeneities in Montana

Very intensive geophysical measurements were made in a small area in the region of the Large Aperture Seismic Array (LASA), Montana. Studies by H. M. Iyer using earthquake data recorded by the seismic array showed that large traveltime residuals exist in this small region. Most of these residuals can be explained by the upper crustal features and by a synclinal structure of the crust-mantle boundary under LASA. The unexplained part of the anomalies indicates that heterogeneities may exist in the upper mantle under LASA. The studies have revealed that even a small slice of the continental crust and upper mantle is far from homogeneous.

#### Tidal power and global heat flow

The hypotheses that tidal power is significant to the balance of global heat flow and to the crustal structure of the earth through the intermediary of igneous processes was proposed by H. R. Shaw (1913). He suggested that the present magnitude of tidal power is sufficient to account for rates of continental growth since the Precambrian by a process analogous to refine-

<sup>50</sup> King, E. R., and Zietz, Isidore, 1970, An aeromagnetic study of the midcontinent gravity high of the central United States: *Geol. Soc. America Bull.* [In press]



ment of the upper mantle by zone melting. This process can account for composition distributions in the continent which, on the average, fit a radioactive source gradient of the exponential type proposed by Lachenbruch.<sup>51</sup>

In oceanic systems the equivalent effect of magma production by tidal power is shortcircuited to higher levels along the oceanic ridges. The corresponding injection rate accounts for a globally averaged spreading from ridges of about 1 cm/yr. Approximate constancy of average heat flow over continents and oceans is implied by distributions or mass-transfer and chemical gradients consistent with the hypothesis of magma production by dissipation of tidal power.

See related study by Shaw on page A125 in the section "Plutonic Rocks and Magmatic Processes."

#### Determination of heat flow from uncored boreholes

Although tens of thousands of holes have been drilled by the oil and mining industries throughout the world, only a few hundred have been found satisfactory for the determination of heat flow from the earth's interior. As a result, this important geophysical quantity is only imperfectly known on the continents. To measure the heat flow it is necessary to measure the geothermal gradient and the heat conductivity of the rock in which the gradient is measured. Most boreholes have been unsuitable because core samples are lacking for the determination of conductivity, but it is common practice to collect and save the fragments of rock returned to the surface by the fluid circulated during drilling. A laboratory method has been devised by J. H. Sass, R. J. Munroe, and A. H. Lachenbruch to reconstruct the conductivity of the unbroken rock from measurements made on such fragments. The method has been verified by the determination of heat flow in holes from which both core and fragments were available. It is expected that this method will lead to the determination of many heat-flow values on parts of the continents where no information is presently available.

### ROCK MAGNETISM

#### Northern Rocky Mountains rock magnetic studies

From paleomagnetic studies on the Boulder and Tobacco Root batholiths, Montana, W. F. Hanna reported that the long period of normal geomagnetic field polarity during Cretaceous time (76 to 71 m.y. ago and possibly 78 to 68 m.y. ago) was interrupted by a short reversed period about 75 m.y. ago. This short reversed period persisted for less than 2 m.y.

#### Mid-Tertiary paleomagnetic pole from the Western United States

Paleomagnetic studies carried out by C. S. Grommé on 67 mid-Tertiary volcanic rocks from Oregon, Nevada, Utah, and California were used to locate a paleomagnetic pole for this period at lat 78° N., long 146° E. This new pole defines a pronounced curvature or kink in the North American polar wandering path for Cretaceous to Holocene time similar to a contemporaneous kink in the Australian path. However, since the path directions differ by 130° in longitude, it must be concluded that true polar wandering, as well as continental drift, took place during this period.

### MECHANICAL PROPERTIES OF ROCKS

Two mechanisms of faulting in rocks, stable sliding and stick-slip,<sup>52</sup> were investigated in detail by J. D. Byerlee. Sliding occurs with low friction between two polished surfaces of rock at low confining pressure, less than 3 kb for gabbro and dunite and less than 1.5 kb for granite, whereas at higher confining pressure movement is by stick-slip, and friction is high. Therefore one cannot extrapolate from the conditions of low-friction on polished surfaces of rock under low pressure to those of rough fault surfaces of rock in the earth, especially for depths greater than 5 km. It may be possible to reduce earthquake shocks by maintaining low effective pressure between the fault surfaces and thus produce stable sliding rather than stick-slip; reduced pressure might be accomplished by fluid injections.

Creep in the ultramafic rock, lherzolite, under high temperature and pressure, was studied by C. B. Raleigh and S. H. Kirby. They determined that such rock in the upper mantle, the upper 200 km of the earth, will flow by creep, with the creep rate proportional to stress raised to the fifth power. In the lower mantle, creep is by the Nabarro-Herring mechanism, and creep rate is directly proportional to stress. Xenoliths of peridotite, presumably of upper mantle origin, contain microstructures like those produced experimentally in the creep range where fifth-power law applies.

Strengths of quartz-rich sedimentary and metamorphic rocks increase with increasing solidity (decreasing porosity) and increase with improvement in grain-to-grain bonding accompanying lithification. These results were found by E. C. Robertson in a study of a suite of graywackes from the Coast Range in California and Oregon. The massive feldspar-quartz rock is more brittle and slightly stronger than the jadeite-

<sup>51</sup> Lachenbruch, A. H., 1968, Preliminary geothermal model of the Sierra Nevada: *Jour. Geophys. Research*, v. 73, p. 6977-6989.

<sup>52</sup> Stick-slip, the brittle failure of rock after buildup of stress in a cyclic process of stress rise and drop.

quartz-glaucophane rock, both with about 1 percent porosity but differing in metamorphic grade. The results indicate that the high-pressure minerals in the blueschist facies rocks can form in the relatively shallow crust without requiring deep burial because of the strength of these rocks.

Direct comparisons of density profiles of soft, highly porous sandstones and siltstones of late Cenozoic and Holocene ages in three California oil wells were made by T. H. McCulloh and L. A. Beyer, using (1) commercial gamma-gamma ("formation density") logging, (2) highly precise borehole gravimeter logging, and (3) direct measurement of core samples. The profiles of in situ rock density measured in these completely independent ways were virtually identical; discrepancies could be accounted for, being due to such things as lack of terrain corrections to gravity data, inadequate calibration of the gamma-gamma tool, or poor hole conditions.

### COMPUTER MODELING OF GEOLOGIC PROCESSES

#### Mathematical modeling of fault-zone tectonics and seismicity

A deterministic computer model which simulates the long-term and transient deformations of shallow seismic faults was developed by J. H. Dieterich (r2317). The model consists of an elastic body which is subjected to a gradually increasing tectonic stress. Slippage on a segment of the fault occurs during an earthquake event when the local stress exceeds the local static friction. Displacement fields between seismic events and acceleration fields during an earthquake are determined using the finite-element method. The average rupture velocity computed for a sequence of 30 earthquakes of magnitude 3.5 to 6.0 is 3.2 km/sec. The drops in fractional stress for these seismic events range from 1 to 12 percent of the total stress. Rupture lengths and amounts of slip are within the range of values observed for real earthquakes with similar magnitudes. Potential applications of the model include the study of earthquake triggering by fluid injection or underground explosions and the study of long-term tectonic deformations of seismically active faults.

#### Thermal evolution of the midoceanic ridges

The midoceanic ridges are major active structures of the earth with a total length of 40,000 miles and an average width of 1,500 miles. They play an important role in the evolution and development of the continents and oceans. Thermal evolution of the midoceanic ridges was studied by W. H. K. Lee using a

two-dimensional model of a spreading sea floor. The heat equation for a semi-infinite spreading slab was solved numerically by a finite-difference method using an alternating direction implicit scheme. Temperature and heat flow across the midoceanic ridges were computed from the model. For the Mid-Atlantic Ridge, a spreading rate of 2 cm/yr yields results which agree with field measurements. For the East Pacific Rise, a spreading rate of 4 cm/yr is required. The results lend support to the hypothesis of sea-floor spreading and plate tectonics.

#### Interpretation methods of gravity, magnetic, and resistivity data

R. G. Henderson and Lindrith Cordell made extensive use of Fourier series and integrals to represent and analyze magnetic and gravity data. For unevenly spaced data on an irregular surface, such as Bouguer gravity data over rough terrain or aeromagnetic data at constant height above ground, a harmonic analysis system was developed to reduce the data to a common level. For evenly spaced data, methods are being developed for deriving geometric parameters of disturbing bodies.

A new method for differential resistivity sounding was developed by A. A. R. Zohdy (r1502). A computer program written originally for computing Schlumberger sounding curves has been modified to calculate transverse differential, longitudinal differential, and all types of dipole-dipole sounding curves obtained over horizontally layered earth models.

### GEOCHEMISTRY, MINERALOGY, AND PETROLOGY

#### GEOCHEMISTRY OF ORE DEPOSITS

##### Low-silver rims on grains of placer gold

On the basis of microscopic and electron-microprobe examination, G. A. Desborough discovered that virtually all placer gold grains from 35 localities in the Western United States and Alaska are surrounded by low-silver rims. He interprets this texture to indicate depletion of silver by an oxidation process, either in the placer environment or prior to liberation from the lode. The cores of grains contain fresh sulfide inclusions indicating that they have not been altered. Bulk assays of placer gold do not reveal the fineness of the gold in the original lode.

##### Minor-element content of sulfide minerals, Darwin mine, Inyo County, Calif.

W. E. Hall, in collaboration with H. J. Rose, Jr., and F. O. Simon investigated the minor-element con-

tent of carefully purified sulfide minerals from the Darwin mine, Inyo County, Calif. Small amounts of silver (up to 0.28 wt percent) occur in direct substitution for lead in the galena, while greater amounts (up to 6.7 wt percent) occur only in coupled substitution with bismuth along the galena-matildite join. Darwin galena also contains as much as 16.5 mole percent clausthalite (PbSe) in solid solution. The distribution of cadmium and manganese between coexisting sphalerite and galena indicate temperatures of deposition of  $435^{\circ}\pm 20^{\circ}\text{C}$  and  $400^{\circ}\pm 50^{\circ}\text{C}$ , respectively. Similar values based on the distribution of selenium are widely scattered. The consistency of the cadmium and manganese distribution data strongly suggests that there is possible application of minor-element distribution to geothermometry.

#### **Concentration of gold by colloidal silica in hot-spring water, Yellowstone National Park**

In their investigations of the geochemistry of hot springs in Yellowstone National Park, J. J. Rowe and R. O. Fournier found that silicious sinter now being deposited from a hot spring with abnormally high silica content is one or two orders of magnitude higher in gold content than sinter being deposited from other springs with normal silica content. The dissolved silica in this spring water exceeds 700 ppm, and the total silica is much higher owing to abundant colloidal silica. The water is boiling and discharging at the rate of 50 to 100 gpm. They concluded that the gold along with arsenic and antimony is adsorbed on the colloidal silica in the water, leading to high concentrations of the metals. Colloidal silica is most readily deposited where organic material is present. The noted association of gold, silica, arsenic, and organic material is very similar to that in the Carlin-type gold deposits.

#### **Multiple exsolution of cobaltian pentlandite from pyrrhotite, Iron County, Mo.**

G. A. Desborough investigated the mineralogical composition of disseminated sulfides in polymineralic aggregates in the gabbro of the Shepard Mountain intrusion, Iron County, Mo., by mineragraphic and quantitative electron-microprobe techniques. The aggregates are interpreted as products of crystallization of an immiscible sulfide-rich melt and consist of pyrrhotite, chalcopyrite, pentlandite, and pure magnetite, and less common cubanite and sphalerite. Pyrrhotite is the most abundant phase. It contains less than 0.2 wt percent Ni or Co in solid solution, but is host to two distinct generations of exsolved pentlandite. The earlier exsolved pentlandite occurs as subhedral crystals up to  $30\mu$  in diameter in pyrrhotite grains which also host later lathlike exsolution lamellae of

pentlandite up to  $10\mu$  in diameter. The early pentlandite contains from 10 to 27 wt percent Co while the later laths contain from 2 to 10 wt percent. The unusually high cobalt contents of both pentlandite phases and the recognition of two generations of exsolution indicate the importance of considering the role of cobalt in the subsolidus relations of the iron sulfide minerals.

## **EXPERIMENTAL GEOCHEMISTRY**

### **Thermodynamic data for mineral assemblages**

A direct method for deriving thermodynamic constants of hydrous silicate minerals for which there are published data on P-T stability limits is being studied by E-an Zen. This procedure uses the actual data for experimental brackets of the stability curve, thereby avoiding some of the uncertainties derived from the more commonly attempted interpretation of smoothed curves of  $\text{H}_2\text{O}$  fugacity versus temperature. Results have been obtained for 2M muscovite, paragonite, anthophyllite, and pyrophyllite, but thus far none can be assigned definitive thermodynamic constants. The method, however, provides a rigorous test for mutual consistency of hydrothermal studies and consistency with calorimetric or other independent studies. As an example, it was found that the average free energy of formation of pyrophyllite (from the elements at  $25^{\circ}\text{C}$ , 1 atm) is about  $-1,251 \text{ kcal/g}^{53}$  formula when it is calculated from data for pyrophyllite produced from kaolinite plus quartz, but the average is  $-1,258 \text{ kcal/g}$  formula when the free energy is calculated for the breakdown of pyrophyllite to andalusite plus quartz. The discrepancy of 7 kcal cannot be accounted for in the uncertainties of the method. Because the thermodynamic data for quartz and  $\text{H}_2\text{O}$  are common to both calculations, suspicion is thrown on the thermodynamic constants for either kaolinite or andalusite (and, by implication, kyanite and sillimanite). Therefore, until the source of error is located no reliable petrologic calculations can be made for any of the aluminosilicates, hydrous or anhydrous.

### **Hydrothermal study of dawsonite**

J. L. Haas, Jr., J. R. Fisher, and E-an Zen made some reconnaissance studies of the stability of synthetic dawsonite,  $\text{NaAl}(\text{OH})_2\text{CO}_3$ , in aqueous solutions at temperatures to about  $300^{\circ}\text{C}$  and at pressures equal to the vapor pressure of the solution. The solutions were buffered by solid sodium carbonate-bicarbonate to control concentrations of sodium and

<sup>53</sup> The kilocalorie, kcal, a unit of energy measurement equal to 1,000 defined calories. The defined calorie is 4.1840 absolute joules.

carbonate ions. It has been found that reactions between dawsonite and other phases such as quartz are sufficiently rapid in these solutions to make rigorous studies of specific reactions feasible. Also, attempts to produce an ammonium analog of dawsonite by ion exchange at 100°C gave evidence of the ammonium phase, but data from X-ray diffraction studies and infrared spectroscopy have not yet established whether this represents isomorphous substitution or complete recrystallization.

#### Electrochemical measurements of oxygen potentials in hydrothermal systems

J. L. Haas, Jr., and J. R. Fisher developed apparatus incorporating a solid electrolyte cell of yttria-doped zirconia as a sensor of the oxygen potential in aqueous solutions which operates by the same principle described by Motoaki Sato.<sup>54</sup> Present findings show that electrode response is satisfactory at temperatures as low as 250°C. Numerous mechanical problems have so far precluded definitive calibration, but tests indicate that the calibration can be made. This apparatus will permit study of solutions and mineral reactions under conditions previously inaccessible and will open up a whole new realm to experimental petrology.

#### Data for ions in aqueous solutions

C. L. Christ and P. B. Hostetler (U.S. Geological Survey) and Elmont Honea (University of Missouri) computed tables of single-ion activity coefficients based on the Debye-Hückel theory for ionic charges from 1 to 4 and effective ion diameters from 2 to 12 Å. The range of conditions covers temperatures from 0°C to 700°C, pressures from 1 to 8,000 atm, and ionic strengths from 10<sup>-4</sup> to 3. The data are being compiled in the form of a handbook for chemists and geochemists.

#### Solubility of minerals in water at low temperatures

Studies in the system MgO-SiO<sub>2</sub>-CO<sub>2</sub>-H<sub>2</sub>O by C. L. Christ and P. B. Hostetler significantly refined data for the solubility of magnesite in water at temperatures from 0°C to 200°C (Christ and Hostetler, r0277, r2217) and have also obtained new data defining the equilibrium constant for solubility of sepiolite at 70°C.

The activity-product constant for solubility of magnesite,  $K_m = [\text{Mg}^{2+}][\text{CO}_3^{2-}]$ , is found to be 10<sup>-8.1</sup> at 25°C. Previous investigations had only restricted  $K_m$  to values between 10<sup>-5</sup> and 10<sup>-10</sup> at 25°C. The new data establish that magnesite is stable with respect to either hydromagnesite or nesquehonite in natural water under

ordinary conditions near the earth's surface. This conflicts with previous laboratory findings but agrees with geologic evidence. The data for magnesite, combined with solubility data for calcite and dolomite, show that below 85°C initially stoichiometric dolomite in contact with initially pure water will gradually become enriched in calcium relative to magnesium. Correspondingly, the water phase will contain elemental ratios of magnesium to calcium exceeding unity. This conclusion is important to problems of dolomitization and dedolomitization.

The equilibrium constant describing the solubility of sepiolite in water is defined by

$$K_{sp} = \frac{[\text{Mg}^{2+}]^2[\text{OH}^-]^4[\text{H}_4\text{SiO}_4]^3}{[\text{H}_2\text{O}]^{4.5}}$$

Experimental data at 70°C give the values  $\log K_{sp} = -37.7 \pm 0.2$  for well-crystallized sepiolite from Balmat, N.Y., and  $\log K_{sp} = -37.2 \pm 0.2$  for a poorly crystallized sepiolite from Eski-Schir, Turkey. Natural sepiolite or sepiolitelike phases are often poorly crystallized and tend to dissolve metastably, yielding solutions more concentrated than those coexisting in equilibrium with the most stable sepiolite. Such metastable solutions may persist over long periods of time. Present results suggest that sepiolite should precipitate from cold interstitial saline water in sediments of marine origin, and that modern saline lake water is supersaturated with respect to sepiolite. The findings agree with geologic evidence on occurrences of sepiolite in these environments.

#### Calorimetry of minerals

The heat capacities from 15°K to 310°K for the minerals nesquehonite, artinite, hydromagnesite, and huntite were measured by R. A. Robie and B. S. Hemingway. These data permit calculations of the molar entropies for these minerals at 298.15°K, and together with data on heats of formation previously obtained in this laboratory, define their Gibbs free energies of formation.

## MINERALOGIC STUDIES IN CRYSTAL CHEMISTRY

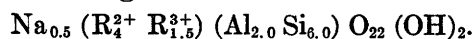
### CRYSTAL CHEMISTRY OF ROCK-FORMING SILICATES

#### Crystal chemistry of orthoamphiboles, variety gedrite

Chemical analyses of orthoamphiboles from metamorphosed volcanic rocks (sillimanite zone) of southwestern New Hampshire and adjacent Massachusetts (Peter Robinson, Malcolm Ross, and H. W. Jaffee, r2579) demonstrate a solid-solution series between an-

<sup>54</sup> Sato, Motoaki, 1966, Electrochemical investigation of the role of oxygen in igneous and metamorphic processes [abs.]: *Am. Geophys. Union Trans.*, v. 47, no. 1, p. 208-209.

thophyllite,  $R_7^{2+}Si_8O_{22}(OH)_2$ , and gedrite,  $Na_x(R_7^{2+}R_y^{3+})(Al_{x+y}Si_{8-x-y})O_{22}(OH)_2$ , where Na (or K) occupies the otherwise vacant *A* site,  $R^{2+} = Mg + Fe^{2+} + Mn + Ca$ , and  $R^{3+} = Al + Fe^{3+}$ . Analyses indicate that the gedrite end member has the formula



The crystal structures of two gedrites approaching end-member composition with the formulas

- (1)  $Na_{0.45}(Na_{0.02}Ca_{0.03}Mg_{4.52}Al_{1.21}Ti_{0.06}Mn_{0.02})_{\Sigma=7}(Al_{1.75}Si_{3.25})_{\Sigma=5}O_{22}(OH)_2$ , and
- (2)  $Na_{0.53}(Na_{0.02}Ca_{0.04}Li_{0.02}Mg_{3.01}Al_{1.36}Fe_{3.36}^{2+}Fe_{0.13}^{3+}Ti_{0.03}Mn_{0.03})_{\Sigma=7}(Al_{2.05}Si_{5.95})_{\Sigma=8}O_{22}(OH)_2$

were determined by J. J. Papike and Malcolm Ross (r2576). Sodium mainly occupies the *A* site, is tightly coordinated by six oxygen atoms, and shows little positional disorder. This contrasts with sodium in the *A* site of clinoamphiboles where sodium shows a high degree of positional disorder and irregular coordination. The significant difference in *A*-site coordination between clino- and orthoamphiboles results from differences in tetrahedral chain rotations around the site. In *C2/m* clinoamphiboles the rotation sense of the tetrahedral chains is the same above and below the *A* site, but in orthoamphiboles the chains rotate in opposite directions on either side of the site. Tetrahedral aluminum is disordered over three of the four distinct tetrahedral sites in these gedrites. The fourth is mainly occupied by silicon. The tetrahedron occupied by silicon shares an edge with an *M*(4) octahedron and is inherently small in size. Octahedral aluminum is concentrated in the *M*(2) site in these structures, and ferrous iron prefers the *M*(4) site over the *M*(1), *M*(2), and *M*(3) sites. Differences in the iron-magnesium distributions in the gedrites from two different localities suggest a difference in thermal history.

From this study of gedrite the basic structural differences of the four known amphibole polymorphs can now be described on the basis of (1) the sense of the rotation of the upper and lower tetrahedral chains relative to the octahedral strips (J. B. Thompson, Jr., r2581), (2) by the orientation of the octahedral strips along the *c*-axis, and (3) by whether there is one type of tetrahedral chain or two, symmetrically distinct.

#### Cation exchange in richterite series amphiboles

J. S. Huebner and J. J. Papike (r2229) proposed a model for the  $Na \rightleftharpoons K$  substitution in the *A* site of alkali amphiboles. They synthesized compositions of the richterite series,  $(K,Na)NaCaMg_5Si_8O_{22}(OH)_2$ , and determined that the unit-cell parameters vary continuously and linearly between the potassic and sodic-end members. The known increase in molar

volume, 3.55 cm<sup>3</sup>/mole, as K substitutes for Na, can be used to estimate the molar volumes of natural potassic amphiboles. Potassic amphibole is denser (smaller molar volume) than the compositionally equivalent assemblage, phlogopite plus pyroxene. Therefore, high pressures characteristic of the mantle should favor the formation of potassium-bearing amphibole instead of producing mica plus pyroxene.

#### Studies of synthetic pyroxenes and pyroxenoids

Pyroxmangite,  $(Mn,Fe,Ca,Mg)SiO_3$ , is a pyroxenoid chain silicate in which the repeat unit of the silicate chains is seven tetrahedra long. Enstatite,  $MgSiO_3$ , is an orthopyroxene chain silicate with two distinct kinds of silicate chains, each having a repeat unit of only one tetrahedron. J. S. Huebner studied the reactions between rhodocrosite,  $MnCO_3$ ; tephroite,  $Mn_2SiO_4$ ; manganosite, "MnO"; and the pyroxenoids rhodonite,  $MnSiO_3$ , and pyroxmangite, all of which constitute a mineral suite observed in many metamorphosed manganese ore bodies. Members of the series  $MnSiO_3$ – $MgSiO_3$  were synthesized at 800°C and 2,000 bars. Using X-ray diffraction powder data, pyroxenoid unit-cell constants were refined and patterns indexed for natural rhodonite, synthetic rhodonite (grown in a  $MnCl_2$  melt with a thermal gradient), and natural pyroxmangite. Comparison of these patterns with those of fine-grained synthetic  $MnSiO_3$  indicates that  $MnSiO_3$  has the pyroxmangite structure. Up to 35 mole percent  $MgSiO_3$  can be accommodated in this pyroxenoid structure, and up to 35 mole percent  $MnSiO_3$  can be accommodated in the orthopyroxene structure of enstatite. Between these one-phase regions, both pyroxenoid and orthopyroxene structures are stable. Pyroxenoids with chain repeat units longer than seven tetrahedra were not observed.

#### AUTOMATION OF X-RAY POWDER DIFFRACTOMETRY

Although measurement of chart peaks representing the angular positions of diffracted X-ray radiation is a useful method for identifying minerals and determining their composition and structure, it is also time consuming and tedious if high accuracy is desired because the measurements must be repeated and averaged. An electronic apparatus has been assembled from standard components to count diffracted X-ray quanta for small increments of angular rotation of the sample and to store these data until they can be recorded on tape. These data are quickly reduced by a computer program to yield peak position, intensity, area, and width, and to correct for background, instrument noise, and the presence of internal standards. Considerable experience has shown that data from a

single angular scan can be refined to yield cell dimensions with a standard error of 1 part in 8,000 (or better) for monoclinic and triclinic minerals. For minerals with higher symmetry, the results are even more precise and, in all cases, are as precise as can be obtained by repetitive measurements by hand. Only one-third the diffractometer time, however, and none of the technician time formerly required are needed. Comparison between observed peak areas and calculated intensities is satisfactory and adequate for indexing powder patterns, whereas formerly only approximate intensity data could be estimated. The apparatus was assembled and computer programs written and developed by D. B. Stewart, J. S. Huebner, and M. S. Hellmann.

### NEW MINERAL DATA

#### Hydroglauiberite, $\text{Na}_4\text{Ca}(\text{SO}_4)_3 \cdot 2\text{H}_2\text{O}$

Inclusions in massive specimens of icelike mirabilite,  $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$ , from Solar de Pintados, northern Chile, were found by M. E. Mrose to consist of colorless fragments of thenardite,  $\text{Na}_2\text{SO}_4$ , and halite in association with dense masses of hydroglauiberite, a snow-white fibrous mineral with silky luster. Hydroglauiberite was first found in salt deposits of Karakalpaksaya, A.S.S.R. (U.S.S.R.) by M. N. Slyusareva<sup>55</sup> who reported the composition to be  $5\text{Na}_2\text{SO}_4 \cdot 3\text{CaSO}_4 \cdot 6\text{H}_2\text{O}$ .

Recalculation of the two original analyses reported for hydroglauiberite led to the simpler formula,  $\text{Na}_4\text{Ca}(\text{SO}_4)_3 \cdot 2\text{H}_2\text{O}$ . Nearly 300 mg of hydroglauiberite from Chile have been purified for chemical analysis in order to corroborate this formula, which corresponds to that given for an acidular double salt found by numerous investigators in the system  $\text{Na}_2\text{SO}_4\text{--CaSO}_4\text{--H}_2\text{O}$ . This phase was found occurring naturally in the Death Valley saltpan and also in Saline Valley, Calif.<sup>56</sup> The optical properties and X-ray powder data of the synthetic and natural phases are in good agreement with those of hydroglauiberite. The single-crystal data have never been determined, and crystals of synthetic hydroglauiberite are being prepared for such study as the natural crystals are too minute for this purpose.

#### New hydrous silicates from California

Two new hydrous silicate minerals and several rare ones were found by R. A. Sheppard and A. J. Gude III in a siliceous spring deposit near Trinity

Center, Trinity County, Calif. The new minerals are a crystalline silica hydrate and a hydrous Na-Ca-K silicate. The rare minerals are kenyaite, magadiite, mountainite, and rhodesite. These rare minerals were previously reported only from Africa, except for magadiite, which was reported by others from several localities in Africa and from Alkali Valley, Oreg. The magadiite is localized along the contact of a Devonian(?) dacite and tremolite schist, and was probably deposited from alkaline, saline springs near the present land surface in the recent past. Springs that issue from the magadiite deposit are exceptionally alkaline (pH=10.3–10.9) and have sodium contents of 8,800 to 11,500 ppm and silica contents of 545 to 800 ppm, but presently do not seem to be precipitating magadiite or any of the other hydrous silicate minerals. Leaching of the magadiite by meteoric water has locally produced kenyaite and a new crystalline phase of silica hydrate to be described. Rhodesite occurs in fractures and along the exterior surfaces of angular fragments of dacite in the magadiite deposit. The new hydrous Na-Ca-K silicate mineral was found only as veinlets in sheared tremolite schist that is saturated with saline water. A transformation of the new mineral to mountainite begins immediately on exposure to the atmosphere and is complete after several days. The transformation apparently involves loss of some water and is accompanied by a structural reorganization.

#### Hydrous manganese silicate

A hydrous manganese silicate that is possibly a new mineral and shows similarity in its crystallographic and chemical properties to orientite,  $\text{Ca}_4\text{Mn}^{3+}\text{Si}_5\text{O}_{20} \cdot 4\text{H}_2\text{O}$ , and to the epidote group of minerals, was found by R. C. Erd, D. F. Hewett, and S. I. Ali (University of Karachi, West Pakistan). The mineral is associated with manganite,  $\text{MnO}(\text{OH})$ , in samples of manganese ores from West Pakistan, and is monoclinic, diffraction aspect  $P2_1/*$ ,  $a=10.21 \pm 0.05$  Å,  $b=6.07 \pm 0.02$ ,  $c=8.96 \pm 0.02$  Å,  $\beta=110^\circ 42' \pm 2'$ . Optically the mineral is biaxial positive with  $\alpha=1.763$ ,  $\beta=1.780$ ,  $\gamma=1.819$ ,  $2V=80^\circ$  (estimated), and is strongly pleochroic with Z (brownish black) > Y (reddish brown) > X (greenish brown). The chemical composition is not yet verified because of the small amount available.

#### NEW CRYSTAL STRUCTURES OF THREE BORATES, TWO VANADATES, AND A HETEROPOLY COMPLEX

##### Strontioginorite, $\text{SrCaB}_{14}\text{O}_{20}(\text{OH})_6 \cdot 5\text{H}_2\text{O}$

Solution of the previously unknown crystal structure of type strontioginorite from Reyershausen, Ger-

<sup>55</sup> Slyusareva, M. N., 1969, Hydroglauiberite, a new mineral of the hydrated sulfate group: *Zapiski Vses. Mineralog. Obshch.*, v. 98, p. 59–62. [In Russian]

<sup>56</sup> Hardie, L. A., 1965, Phase equilibria involving minerals of the system  $\text{CaSO}_4\text{--Na}_2\text{SO}_4\text{--H}_2\text{O}$ : *The Johns Hopkins Univ., Baltimore, Md.*, unpub. Ph. D. thesis, 317 p.

many,<sup>57</sup> by J. A. Konnert, J. R. Clark and C. L. Christ confirmed the composition of the mineral as  $2(\text{Sr,Ca})0.7\text{B}_2\text{O}_3 \cdot 8\text{H}_2\text{O}$  and revealed that it contains a new kind of boron-oxygen polyanion,  $[\text{B}_{14}\text{O}_{20}(\text{OH})_6]^{4-}$ . The crystal studied has a Sr-Ca ratio of 1, determined through X-ray milliprobe analysis by H. J. Rose, Jr., and R. P. Christian, and is monoclinic,  $P2_1/a$ , with  $a=12.817$  Å,  $b=14.448$  Å,  $c=12.783$  Å (all  $\pm 0.008$  Å),  $\beta=101.42 \pm 0.08^\circ$ ,  $V=2,320$  Å<sup>3</sup>,  $Z=4$  [ $\text{SrCaB}_{14}\text{O}_{20}(\text{OH})_6 \cdot 5\text{H}_2\text{O}$ ], and density =  $2.265$  g cm<sup>-3</sup> (calculated). The  $[\text{B}_{14}\text{O}_{20}(\text{OH})_6]^{4-}$  polyanion is formed by corner-sharing between two crystallographically distinct tunnellite-like polyanions,<sup>58</sup> one of which has attached a linear side chain of composition  $[\text{B}_2\text{O}_2(\text{OH})_3]^{1-}$ , the dimer of boric acid. The establishment of this type of polymerization in hydrated borates significantly extends the principles governing the formation of complex borate polyanions in crystals.<sup>59</sup>

#### Fabianite, $\text{CaB}_3\text{O}_5(\text{OH})$

The mineral fabianite found in salt deposits from Diepholz, Germany,<sup>60</sup> has the same composition as synthetic  $\text{CaB}_3\text{O}_5(\text{OH})$  for which the structure was determined by J. R. Clark, C. L. Christ, and D. E. Appleman.<sup>61</sup> The synthetic is orthorhombic,  $Pbn2_1$ ,  $a=6.97$  Å,  $b=13.47$  Å,  $c=4.39$  Å, whereas fabianite is monoclinic,  $P2_1/a$ ,  $a=6.593$  Å,  $b=10.488$  Å,  $c=6.365$  Å,  $\beta=113.38^\circ$ . The crystal structure of fabianite, solved by Clark, J. A. Konnert, and Christ (r0278) was found to contain the same borate polyanion sheets as does the synthetic, but in the mineral these are arranged more compactly so that Ca is 8-coordinated instead of 7-coordinated as in the synthetic. The more compact packing probably results from conditions of formation different from those of the synthetic which was prepared hydrothermally from inyoite at 400°C and 2,000 bars.

#### Hulsite, an Fe-Mg-Sn borate

J. A. Konnert, D. E. Appleman, and J. R. Clark determined that the crystal structure for hulsite, an iron borate mineral from Brooks Mountain, Seward

Peninsula, Alaska,<sup>62</sup> has a variable composition assumed to be  $\text{Sn}_{0.20}\text{Fe}_{1.50}\text{Fe}_{0.65}^{3+}\text{Mg}_{0.65}\text{BO}_3\text{O}_2$ , monoclinic symmetry,  $P2_1/m$  space group,  $a=10.648$  Å,  $b=3.099$  Å,  $c=5.438$  Å,  $\beta=94.14^\circ$ , and  $Z=2$ . The structure contains two kinds of octahedral chains parallel to  $c$ . One chain is a staggered configuration made up of two crystallographically independent octahedra sharing edges, one occupied by Sn and Fe, the other by Mg and Fe. By further sharing edges, these chains link with the equivalent chains in the cells above and below to form sheets of octahedra parallel to (100). The second kind of chain is a twisted form composed of three crystallographically independent octahedra, each sharing two edges with the others. Two of these octahedra contain Fe, Sn, and Mg; the other contains primarily Fe plus Mg. The two kinds of chains link by corner-sharing among octahedra as well as by corner-sharing between octahedra and the boron-oxygen triangles. The related structure of ludwigite has only four crystallographically distinct octahedra.

#### Cavansite, $\text{Ca}(\text{VO})(\text{Si}_4\text{O}_{10}) \cdot 4\text{H}_2\text{O}$ , and synthetic $\text{Ca}_2\text{V}_2\text{O}_7 \cdot 2\text{H}_2\text{O}$

Cavansite, a new mineral from Oregon,<sup>63</sup> is an orthorhombic layer silicate,  $Pcmn$ ,  $a=9.792$  Å,  $b=13.644$  Å,  $c=9.629$  Å (all  $\pm 0.002$  Å),  $V=1,258.5$  Å<sup>3</sup>, cell contents are  $4[\text{Ca}(\text{VO})(\text{Si}_4\text{O}_{10}) \cdot 4\text{H}_2\text{O}]$ , density =  $2.38$  g cm<sup>-3</sup> (calculated). H. T. Evans, Jr., found that the silicate layers in the structure are of a novel type because apices of the alternate tetrahedra in one layer point up and down instead of all in the same direction as in the mica structure. The vanadyl groups lie in mirror planes between the layers and form square pyramids by using two apices from each of two adjacent layers.

J. A. Konnert and H. T. Evans, Jr., solved the structure of a synthetic triclinic calcium vanadate,  $\text{CaV}_2\text{O}_7 \cdot 2\text{H}_2\text{O}$ , which has space group  $P\bar{1}$ , with  $a=8.125$  Å,  $b=8.201$  Å,  $c=6.862$  Å,  $\alpha=96.25^\circ$ ,  $\beta=113.27^\circ$ ,  $\gamma=106.20^\circ$ ,  $V=390.7$  Å<sup>3</sup>,  $Z=2$ , and density =  $2.80$  (calculated),  $2.81$  g cm<sup>-3</sup> (measured). The crystal has pyrophosphatelite, double tetrahedral  $(\text{V}_2\text{O}_7)^{4-}$  ionic groups, and there is a structural resemblance to members of a previously studied series.<sup>64</sup>

<sup>57</sup> Braitsch, O., 1959 Uber Strontfoginorit, eine neue Ginorit-Varietät aus dem Zechsteinsalz: Beitr. Mineralog. Petrographie, v. 6, p. 366-370.

<sup>58</sup> Clark, J. R., 1964, The crystal structure of tunnellite,  $\text{SrB}_6(\text{OH})_2 \cdot 3\text{H}_2\text{O}$ : Am. Mineralogist, v. 49, p. 1549-1568.

<sup>59</sup> Christ, C. L., 1960, Crystal chemistry and systematic classification of hydrated borate minerals: Am. Mineralogist, v. 45, p. 334-340.

<sup>60</sup> Kühn, Robert, 1962, Fabianit,  $\text{CaB}_3\text{O}_5(\text{OH})$ , ein neues Mineral: Kali u. Steinsalz, v. 9, p. 285-290.

<sup>61</sup> Clark, J. R., Christ, C. L., and Appleman, D. E., 1963, Studies of borate minerals (X)—The crystal structure of  $\text{CaB}_3\text{O}_5(\text{OH})$ : Acta Cryst., v. 15, p. 207-213.

<sup>62</sup> Knopf, A., and Schaller, W. T., 1908, Two new boron minerals of contact-metamorphic origin: Am. Jour. Sci., v. 25, 4th ser., p. 323-331.

<sup>63</sup> Staples, L. W., Evans, H. T., Jr., and Lindsay, J. R., 1968, Cavansite, a new calcium vanadium silicate mineral [abs.]: Geol. Soc. America Spec. Paper 115, p. 211-212.

<sup>64</sup> Brown, I. D., and Calvo, Crispan, 1970, The crystal chemistry of large cation dichromates, pyrophosphates, and related compounds with stoichiometry  $\text{X}_2\text{Y}_2\text{O}_7$ : Jour. Solid State Chemistry, v. 1, p. 173-179.



**Heteropoly complex  $(\text{NH}_4)_6[\text{H}_4\text{Co}_2\text{Mo}_{10}\text{O}_{38}]\cdot 7\text{H}_2\text{O}$** 

The crystal structure of  $(\text{NH}_4)_6[\text{H}_4\text{Co}_2\text{Mo}_{10}\text{O}_{38}]\cdot 7\text{H}_2\text{O}$  was solved by H. T. Evans, Jr. (U.S. Geological Survey), and J. S. Showell (National Science Foundation) (r1526). The monoclinic structure has a new heteropoly complex ion with a double octahedral group surrounded by 10 condensed  $\text{MoO}_6$  octahedra. A review of the relationship of this compound to other isopoly and heteropoly complexes, and their chemical significance, by H. T. Evans, Jr., is nearing completion.

**GLADSTONE-DALE LAW AND CRYSTAL STRUCTURES**

For a number of hydrated calcium borates, the mean index of refraction, calculated by the Gladstone-Dale law, is in amazing agreement with the measured mean value for those substances for which precise optical data and densities from calculated precise X-ray unit-cell data are available. G. D. Eberlein and C. L. Christ found that the excellent agreement is independent of the type of structure—that is, whether the substance contains isolated polyanions, chains, or sheets. In the application of the Gladstone-Dale law, specific refractive energies of the oxide components are used. The fundamental reason why this method works is that in a crystal the oxygens are neutralized on a local basis (Pauling's rule) so that in this broad sense the crystal does, in fact, consist of oxides.

**VOLCANIC ROCKS AND PROCESSES****VOLCANIC ACTIVITY****Kilauea Volcano, Hawaii**

Eruptive activity was extraordinarily persistent on the upper east rift zone of Kilauea Volcano during 1969 and early 1970 and continued at least until April 1970. Much of the effort of the Hawaiian Volcano Observatory staff, headed by H. A. Powers, was devoted to studies of this activity and related ground deformation and earthquake activity.

An eruption from the east rift of Kilauea Volcano began on the morning of February 22, 1969—the third east rift eruption since August 22, 1968. A swarm of short bursts of tremor and small earthquakes (largest of magnitude 2.6) started at about 06<sup>h</sup>27<sup>m</sup>, and by 09<sup>h</sup>00<sup>m</sup> tremor was continuous. As in earlier east rift eruptions, the epicenters of earthquakes were concentrated in two principal zones before and during early eruption—(1) near the site of eruption and (2) in Kilauea caldera. The eruption began at 09<sup>h</sup>50<sup>m</sup> from fissures about 500 m east of Alae Crater; during the next several hours, more fissures opened, and the eruption spread westward into Alae and eastward to Kane Nui o Hamo. A flow originating near Kane Nui o

Hamo spilled into Makaopuhi Crater and also advanced down the Chain of Craters Road to a point about 2.3 km below Makaopuhi. A second flow crossed the Chain of Craters Road midway between Alae and Makaopuhi. By early afternoon, the eruptive fissures had crossed the Chain of Craters Road west of Alae, and they continued to spread westward for the next 4 hours to a point due south of Aloi Crater. Fountaining died out west of Alae during the night of February 22–23, but sporadic activity continued in Alae and from a vent near Kane Nui o Hamo for the next 5 days.

When the eruption ended,  $7 \times 10^6 \text{ m}^3$  of lava was ponded in Alae to a level 75 m above the 1963 lake surface. A nearly continuous row of low spatter cones extended from Alae to due south of Aloi, and two larger cones had formed between Alae and Kane Nui o Hamo. Lava from vents near Kane Nui o Hamo had spread 3 to 5 km eastward, and several disconnected pads of new lava had oozed from isolated segments of the eruptive fissures farther downrift. The total volume of erupted lava was about  $17 \times 10^6 \text{ m}^3$ .

The second flank eruption of 1969 began from a fissure between Alae and Aloi Craters on May 24, and the fissure soon spread westward to 2 km west of Aloi, into what had heretofore been considered a part of the noneruptive Koae fault zone. The fissures are parallel to, but several hundred meters north of, the February vents. By May 26, activity had become concentrated along a short fissure segment midway between Aloi and Alae. Since then, 12 phases of high fountaining and major lava output have taken place, and the eruption is still continuing.

The episodes of vigorous activity have been spaced 2 days to 9 weeks apart and have been separated by periods of weak but persistent activity with or without surface eruption of lava. The fountains have ranged from 30 to 540 m in height and, on their downwind side, a cone of welded spatter about 60 m above the pre-eruption ground surface has been built. Most strong eruptive phases have lasted less than 10 hours, with fountain activity building gradually (within an hour or two) but ending very abruptly (within a few minutes.)

During periods between the episodes of high fountaining, lava usually has been visible in the vent at a depth of several tens of meters or less. For most of this time, the top of the lava column has remained at a fairly constant depth with little or no spattering. Commonly, however, the column has risen and fallen cyclically. During such cycles, the column has risen within the vent without much gas emission; suddenly, with vigorous degassing, the column then has dropped rapidly with violent spattering. This cyclic rise and

fall, which has occurred 25 percent or more of the time between major fountaining episodes, has had a period of 10 to 45 minutes with the fall taking only 2 to 4 minutes of the cycle. This type of activity can be watched safely from the edge of the vent, and it can also be monitored on the Kilauea seismometer network which records harmonic tremor of moderate amplitude during falls and slight tremor during rises. The rising lava column has reached the ground surface and erupted small flows many times. These flows have generally been confined to the vent area but at times have reached both Aloi and Alae Craters. Fountaining has also occurred between major episodes of eruption, but at a much reduced level from that of the virgorous activity. Commonly the fountains have had a domelike appearance, like that of a flowing artesian well.

A lava dome more than 50 m high and 500 m in diameter has been built around the vent area. The dome consists of flows erupted during the numerous periods of comparatively quiet overflowing of the vent, as well as spatter and flows produced by the major eruptive episodes.

To date, flows have completely filled Alae Crater and partly filled Aloi Crater; one flow on June 25 reached the ocean, about 12 km south of the vent. A thick accumulation of pumice and spatter blankets an area several square kilometers downwind from the vent area. Both pahoehoe and aa flows have been produced, and many rootless aa flows fed by welded spatter gliding from the oversteepened flanks of the new cone extend short distances downslope.

No chemical analyses are yet available, but all the new lavas erupted from May 1969 to April 1970 appear to be olivine-bearing tholeiitic basalts. The bulk of the lava from each strong phase of activity is poor in olivine, but the last lava erupted is generally enriched in olivine, suggesting emptying of a magma chamber in which olivine is settling. All lava erupted during periods between phases has been olivine poor. The average monthly output of lava, most of which has been erupted during the episodes of major fountaining, has been about  $10^7$  m<sup>3</sup> (May 24, 1969, through December 31, 1969).

The two flank eruptions in 1969, as well as the two in 1968, have been accompanied by significant ground deformation, both at the summit and along the east rift. The summit of Kilauea has subsided a maximum of 10 to 20 cm in response to each of the upper east rift eruptions in August and October 1968 and February 1969. Accompanying maximum strains and horizontal displacements were: inward ground tilt, 50 to 90 microradians; contraction (tangential to sub-

sidence contours), 50 to 150 ppm; dilatation, -80 to -150 ppm; and absolute ground displacement toward the center of subsidence, 12 to 20 cm. This release of strain was virtually completed within the first 1 or 2 days of each eruption, during which time the center of deflation migrated 2 to 3 km southward from its initial location in the south-central part of Kilauea caldera. Altitude and ground tilt returned approximately to preeruption levels between eruptions, but horizontal strains did not reach their pre-August 1968 levels until December 1969.

Subsidence during the first outbreak of the current upper east rift eruption (May 1969-1970) was only 30 to 50 percent that of the previous eruptions. Release of strain during subsequent vigorous episodes of the current eruption has amounted to 20 to 40 ppm, approximately equal to buildup of strain between the episodes. Interpretation of these data, using a point-source model and three-dimensional displacements, suggests foci of inflation and deflation at depths of 2 to 3 km; the greater depth is located beneath the area of last subsidence or uplift. The inflation and deflation could be caused by either an expanding and contracting magma "chamber" or a rising and falling magma column.

Subsidence at the summit of Kilauea during each east rift eruption since August 1968 has been accompanied by uplift of areas on the east rift near the sites of eruption. These uplifts have ranged from 15 to 90 cm, and bench marks have been displaced away from the rift by as much as 58 cm. During the August 1968 and February and May 1969 eruptions, the crests of uplifted areas cracked and central grabens formed locally. On August 4, 1969, a fault zone intersecting Alae Crater reopened and allowed  $10^7$  m<sup>3</sup> of ponded lava to drain from the crater. A graben more than 40 m deep and 10 m wide formed where the fault zone dilated 2.9 m. Further extension of a 900-m distance across the rift zone near the site of the May 1969-April 1970 eruption has amounted to 8 cm as of January 1970, and possibly reflects rift dilation caused by emplacement of dikes.

This suggested dilation of the east rift is further supported by measured extensional strain across the Hilina fault system about 5 km to the south. Over the period of 1968-70 east rift eruptions, a 5-km distance across part of the Hilina system has shown more than 30 cm of contraction, suggesting that faults within the Hilina system are closing in response to a southward-directed compressional force caused by dike injection within the dilating rift zone to the north.

### **Fernandina Volcano, Galapagos Islands**

K. A. Howard (U.S. Geological Survey) and T. E. Simkin (Smithsonian Institution) reported<sup>65</sup> that the volcanic explosions which preceded the collapse of Fernandina caldera in June 1968 produced an ash cloud which rose 25 km above the volcano and were accompanied by an air wave comparable to that from a large nuclear blast ( $10^{21}$  ergs). The explosions were probably phreatic, caused by lake or ground water gaining access to hot rock as the magma withdrew. Further withdrawal caused the caldera floor to tilt downward as much as 300 m along a ring fault. Analysis of the resulting earthquake swarm suggests that frictional resistance decreased as the collapse proceeded, and that much of the faulting was aseismic.

### **Lassen Volcano, Calif.**

Repeated late-glacial and postglacial dacitic volcanism in Lassen Volcanic National Park, Calif., has been restricted to an area of only about 7 sq mi that extends northward from Lassen Peak. According to D. R. Crandell and D. R. Mullineaux, three eruptive episodes within the last 12,000 years or so have each included initial pyroclastic eruptions and pumice flows, followed by the formation of one or more volcanic domes. The volcanic activity within the park from 1914 to 1917, however, did not follow this pattern in that nearly all the eruptions were small, pyroclastic eruptions were not accompanied by pumice flows, and both pyroclastic debris and a small lava flow were erupted from a crater within the dome of Lassen Peak. The restriction of the most hazardous types of volcanism to a small zone suggests that use of closely adjacent areas will be accompanied by a relatively high degree of risk from future volcanism.

### **Historic pillow basalt**

Fluid basaltic lava, when it cools underwater, commonly forms pillow-shaped masses, and such pillow lavas have been photographed in many places on the ocean floor by remote camera systems. J. G. Moore has discovered perhaps the first locality where fresh submarine pillow lava can be reached by scuba divers, and can be easily sampled and studied. The locality is on the submarine extension of the 1801 lava flow from Hualalai Volcano on the west cape of the island of Hawaii. The lava flow has been explored in nine places to depths of 130 feet. The pillows are covered with a thin layer of calcareous material, beneath which the outer glassy shell of the pillows has been altered through a thickness of  $20\mu$  to  $30\mu$  to yellow-

brown palagonite. Because the age of the pillows is known, the thickness of the alteration layer provides evidence on the rate of submarine weathering.

## **CHEMISTRY OF VOLCANIC ROCKS AND GASES**

### **Oxygen fugacity of mid-Atlantic submarine basalt**

The oxygen fugacity of submarine basalt from the Reykjanes Ridge southwest of Iceland was determined by Motoaki Sato. The basalt which is quite fresh and vesicular was dredged by the research ship *Trident* (University of Rhode Island) from a depth of 1,020 m near the center of the ridge. The log  $f_{O_2}$  value of this basalt at  $1,200^\circ\text{C}$  is  $-8.9$ , which is considerably higher than that of a dredged submarine basalt from Kilauea Volcano, Hawaii. The very high magnetic anomaly measured at the Reykjanes Ridge locality ( $+1,800$  gammas) may be due to the high oxidation state of this basalt.

### **Device for measuring sulfur content of volcanic gases**

An electrochemical probe for measuring the sulfur fugacity of fumarolic gases was developed by Motoaki Sato. The probe consists of a silver internal reference, a porous tube of an inert medium soaked with molten silver chloride (electrolyte), and an external film of silver sulfide. It operates on the principle that the activity of silver in the silver sulfide film varies with the fugacity of sulfur in the gas and that an electric potential is developed between the film and the internal silver reference across the electrolyte. The probe was tested successfully at Sulfur Bank, Hawaii Volcanoes National Park, by R. L. Tuthill.

### **Oxygen fugacity of phenocrysts from Hawaiian basalt**

Motoaki Sato (U.S. Geological Survey) and A. T. Anderson (University of Chicago) determined the oxygen fugacities as a function of temperature of phenocrysts and of the whole rock for the 1955 lava from Kilauea Volcano, Hawaii. The oxygen fugacity-temperature curves for augite, olivine, and hypersthene phenocrysts intersect that of the bulk rock at  $1,180^\circ\text{C}$ ,  $1,130^\circ\text{C}$ , and  $1,120^\circ\text{C}$ , respectively. These temperatures represent the average theoretical crystallization temperatures of the phenocrystic minerals, and agree well with other evidence of the sequence and temperature of crystallization. Since the curve for the oxide phenocrysts (ilmenite-magnetite composite) does not intersect that of the bulk rock, the oxide phenocrysts apparently did not crystallize from the host liquid, but rather from a liquid of high  $f_{O_2}$  (oxidized or more fractionated) and were later caught up in a different liquid. This conclusion is supported

<sup>65</sup> Simkin, Tom and Howard, K. A., 1970, Caldera collapse in the Galapagos Islands, 1968: *Science*, v. 169, no. 3944, p. 429-437.

by textural evidence observed by Anderson and T. L. Wright.

#### Phosphorus content as indicator of crystallization differentiation in basalt

A. T. Anderson (University of Chicago) and L. P. Greenland<sup>66</sup> reported that the distribution factors of phosphorus (P in mineral/P in liquid) between phenocryst minerals and coexisting basaltic groundmass are: olivine ( $Fa_{20}$ ), 0.04 to 0.02; orthopyroxene ( $Fs_{20}$ ), 0.01; augite, 0.02 to 0.01; plagioclase, 0.02; ilmenite, 0.04. Because of the smallness of these distribution factors, the ratio of phosphorus in the initial liquid to that in the residual liquid (phosphorus ratio) ideally equals the mass fraction of residual liquid minus 0.00 to 0.04. The phosphorus ratio facilitates, therefore, quantitative comparison of the variation of major and minor elements with crystallization of basaltic liquids.

A phosphorus fractionation diagram is a log-log graph of the weight percent of any chemical element or oxide plotted against the phosphorus ratio. The slopes of variation curves on such a fractionation diagram approximately equal unity minus the crystal aggregate/liquid distribution factor. Knowledge of the individual mineral/liquid distribution factors makes it possible to estimate the relative proportions of crystallizing minerals from the slopes of curves on a phosphorus fractionation diagram prior to the crystallization of apatite or other phosphorus-rich minerals. This was done fairly successfully for the Alae Lava Lake, Hawaii.

#### Uranium loss from crystallized silicic volcanic rocks

In several suites of silicic volcanic rocks analyzed by J. N. Rosholt and D. C. Noble, the uranium and thorium content of the hydrated glass is nearly identical to or just a few percent lower than that of the associated nonhydrated glass, indicating that no measurable quantity of uranium was removed from the glass during the process of hydration. The thorium content of the crystallized specimens is nearly the same as that in the glasses from the same unit. The uranium content of the crystallized specimen, however, is less than that of the comparable nonhydrated glass. Because all the evidence indicates that the uranium content of the nonhydrated glass represents the original uranium content of the rock units, apparently the uranium was lost by the crystallized groundmass

material. Thus, the crystallized specimens have lost from 30 to 80 percent of the uranium originally present in the rocks. This loss probably was caused by ground-water leaching which was facilitated by oxidation of part or all of the uranium during crystallization. A reasonable conclusion is that many, and probably most, crystallized silicic and intermediate volcanic rocks of Cenozoic age have been affected in a similar manner.

#### XENOLITHS IN BASALT

##### Nunivak Island, Alaska

J. M. Hoare and W. H. Condon found abundant ultramafic nodules, principally lherzolite, in angular xenoliths of olivine tholeiite ejected from Nanwaksjiak Crater on Nunivak Island, Alaska. Lherzolite nodules are common in nephelinitic basalts on Nunivak Island and elsewhere in the world, but this is their first known occurrence in tholeiitic basalt. They provide direct evidence that tholeiitic magma originates at mantle level because lherzolite is a mantle rock, according to most authorities. This evidence supports seismic data which places the origin of tholeiitic magma as deep as 60 km in Hawaii.

The common occurrence of subcrustal rock in highly alkalic basalts and their usual absence in tholeiitic basalts, although both come from the subcrust, is probably related to the time required for the two types of magma to reach the surface from subcrustal level. Highly alkalic magmas are heavily charged with volatile material and erupt violently. They commonly rise fast enough to transport the heavy inclusions to the surface before they are resorbed. Tholeiitic magma is much poorer in volatile material and consequently usually rises too slowly to bring subcrustal rock to the surface before they are resorbed by the magma. The unusual occurrence of subcrustal rock in tholeiite at Nanwaksjiak Crater is probably due to an abnormally high gas content in the tholeiite magma which was intruded beneath the crater toward the close of the highly alkalic eruption that excavated the crater.

Although subcrustal inclusions are extremely rare in tholeiitic basalt, mafic and ultramafic inclusions of crustal origin are common in them because such inclusions need to be transported only a short distance before they reach the surface; furthermore, crustal inclusions are nearly in equilibrium with the tholeiitic host basalt, having probably crystallized from tholeiitic magma during an earlier period of volcanic activity.

<sup>66</sup> Anderson, A. T., and Greenland, L. P., 1969, Phosphorus fractionation diagram as a quantitative indicator of crystallization differentiation of basaltic liquids: *Geochim. et Cosmochim. Acta*, v. 33, p. 493-505.

### Salt Lake Crater, Hawaii

In further and more detailed studies of garnet pyroxenite xenoliths from Salt Lake Crater, E. D. Jackson and M. H. Beeson reported the textures of these xenoliths to be dominated by unmixing caused by partial reequilibration. Garnet and orthopyroxene have exsolved in large amounts from original clinopyroxene grains, and garnet and clinopyroxene have exsolved from original orthopyroxene grains. All the xenoliths are now garnet pyroxenite, but textural reconstruction permits them to be divided into four original rock types: (1) clinopyroxenite, (2) websterite, (3) garnet websterite, and (4) garnet clinopyroxenite. Bulk chemical compositions of these xenoliths define a coherent nearly linear trend intersecting the field of Honolulu lava compositions at one end. The trend in bulk chemistry, and similar trends in both observed and reconstructed mineral chemistry, probably resulted from fractionation processes in the mantle. Comparison of whole-rock compositions and mineralogy of the xenoliths with those expected for fractionation in the experimental system  $\text{CaSiO}_3\text{--MgSiO}_3\text{--Al}_2\text{O}_3$  at 30 kb further supports the idea that fractional fusion, rather than fractional crystallization, was the dominant process in the origin of the xenoliths.

### Honolulu Volcanic Series, Hawaii

E. D. Jackson and T. L. Wright showed that the rocks of the Honolulu Volcanic Series are compositionally zoned with respect to the Koolau shield; near the caldera the predominant rocks are melilite-nepheline basalts, but these give way outward to nepheline basalts, and ultimately, at the apron of the shield, to alkalic olivine basalts. The xenoliths in Honolulu basalts are likewise zoned—most of those in the caldera area consist of dunite, most of those at intermediate distances of lherzolite, and many of those in the apron of the shield consist of garnet pyroxenite and peridotite. The zoning of the xenoliths, however, does not coincide with that of the enclosing rocks. Jackson and Wright believe that copious eruption of Koolau tholeiite produced a lateral and vertical heterogeneity in the mantle beneath Oahu, and that the much smaller volume of the xenolith-bearing Honolulu lavas is due to that heterogeneity. The textures of the xenoliths indicate that the basalts were mainly produced by fractional melting rather than fractional crystallization. There is some evidence that the dunite xenoliths are mantle residua produced during the generation of the tholeiite, and that the Honolulu magma was generated at greater depth than the Koolau magma, and probably as a result of elastic unloading.

### PLUTONIC ROCKS AND MAGMATIC PROCESSES

#### Colville batholith is a gneiss dome

Recent studies in northern Okanogan County, Wash., by K. F. Fox, Jr., and C. D. Rinehart indicate that the protoclastic western border of the Colville batholith is apparently the western edge of a large roughly elliptical gneiss dome, about 50 miles long and 25 miles wide, whose major axis is oriented north-south. The dome contains layered paragneiss in its central and eastern sectors that is flanked to the west and south by a semicircular arc of homogeneous granodioritic gneiss. Flat, undulating gneissosity and a persistent west-northwest-trending lineation suggest nearly horizontal tectonic transport to the south-southwest. Presumably the layered paragneiss, with a thick envelope of granodioritic gneiss, rose along a north-northwest-trending root zone and was deflected to the southwest, creating a thick tabular body. Wallrocks along most of the contact are crushed and brecciated, the degree of cataclasis increasing from north to south. Metasediments at the southwest margin appear to be peeled back in a series of imbricate slices. Brittle failure of the wallrocks, narrow thermal metamorphic aureole, virtual absence of satellitic dikes (except pegmatites), and lack of inclusions of wallrocks in the rock of the gneiss dome suggest emplacement of the dome at shallow depth as a relatively cool plastic mass. The age of the dome is bracketed between the Triassic age of some of the brecciated wallrocks, and undisturbed Eocene volcanic rocks overlying the brecciated contact zones. Potassium-argon and fission-track ages by J. C. Engels suggest emplacement of the gneiss dome about 60 m.y. ago.

#### Exotic gabbros offer clues to continental edge geology

D. C. Ross found that hornblende quartz gabbro and anorthositic gabbro slivers in the San Andreas fault zone at Logan and Gold Hill in the California Coast Ranges may be offset slices of a gabbroic suite exposed on the north flank of the San Emigdio Mountains. These outcrops, made up mainly of gabbro, pyroxenite, hornblende quartz diorite-gabbro, and fine-grained metamorphosed igneous rocks with relict diabasic texture, are north of the gneissic and granitic outcrops of the San Emigdio Mountains and are separated from them by Tertiary rocks. These gabbroic rocks have features that suggest that they may be remnants of ophiolitic ocean crust that is probably the basement for much of the Franciscan terrane. The nearby San Emigdio granitic basement may be part of the Sierra Nevada basement. If both the Francis-

can and Sierra Nevada terranes are present in this area it may be another tie point along the major crustal break between them—a possible preserved remnant of a fossil subduction zone between oceanic and continental material. If so, this is the southernmost exposure of the major break between Sierra Nevada granitic basement and Franciscan rocks on the east side of the San Andreas fault. The easterly trend of the contact between the gabbroic terrane and the granitic basement in the San Emigdio Mountains is just the sort of drag effect that right-lateral movement on the San Andreas fault zone would be expected to produce on the normally north-northwest-trending Franciscan-Sierra Nevada basement contact.

#### Unusual layering in Sierra Nevada rocks

J. G. Moore and J. P. Lockwood (r0952) studied unusual layering at several localities in the Sierra Nevada that appears to be concentrated near the contact of some mafic granitic plutons. The layers are characterized by crystals whose long axes are oriented perpendicular to the plane of the layering. Layering is accentuated by variable amounts of plagioclase, hornblende, and pyroxene. This type of layering, first described by Taubeneck and Poldervaart<sup>67</sup> and called by them "Willow Lake-type layering," generally occurs in the Sierra Nevada in inverted troughs in overhanging walls of the parent pluton. Direction of layer growth, which can be established by widening and branching of crystals, is always toward the parent pluton. The preservation of elongate crystals perpendicular to the plane of the layering, especially delicately branched plagioclase, suggests crystallization from a moving fluid of low viscosity. Occurrence of Willow Lake layers in troughs on overhanging chamber walls suggests crystallization from a low-density fluid, possibly a separate, supercritical aqueous phase, concentrated by gravitative rise from adjacent denser and more viscous melt. The close association of orbicular granites with Willow Lake layering suggests that orbicles were produced by the accretion of Willow Lake layers on xenoliths which were caught in troughs containing the low-viscosity aqueous fluid through which they settled.

#### Late biotite and hornblende in the Coast and Transverse Ranges

F. C. W. Dodge and D. C. Ross suggested that biotites and hornblendes in granitic rocks near the San Andreas fault in the Coast and Transverse Ranges of California generally have crystallized late

relative to the felsic minerals. Based on recent experimental studies on natural materials, this indicates that the ferromagnesian minerals crystallized within a narrow range of water pressures, at water pressures less than about 1 kb. Compositions of eight selected pairs of coexisting hornblendes and biotites suggest that the two minerals formed in an unbuffered and closed system with respect to oxygen. Compositions of hornblendes and biotites from the Southern California batholith are similar to those of the Coast and Transverse Ranges; however, pairs of the minerals from the Sierra Nevada batholith suggest crystallization in a closed but buffered environment. Conditions suggested by hornblende-biotite pairs of the Sierra Nevada probably are more common during plutonic crystallization than are conditions suggested by these mineral pairs from the Coast and Transverse Ranges.

#### K<sub>2</sub>O an index to intrusive sequences in the Sierra Nevada

Analysis of chemical data by P. C. Bateman and F. C. W. Dodge (r0295) showed convincingly that K<sub>2</sub>O decreases systematically westward across the central part of the Sierra Nevada batholith, that CaO probably increases westward, and that FeO and MgO may increase. The ratio  $\frac{K_2O}{SiO_2 - 45}$  decreases westward in steps that coincide with six provisionally established intrusive sequences of granitic rocks. In this ratio, 45 is subtracted from the percent of SiO<sub>2</sub> to shift the coordinate system because the trend line for each sequence projects to zero K<sub>2</sub>O at about 40–45 percent SiO<sub>2</sub>. This allows each sequence to be characterized by a single number. Compositional trends within sequences are different from the compositional changes that take place across the batholith, showing that rocks in the western Sierra are not identical with rocks found at depth beneath the eastern Sierra Nevada. The results are consistent with both the anatectic and seismic zone models for the origin of the batholith.

#### Five intrusive epochs in western North America Cordillera

Intrusion of Mesozoic batholiths in California and the western North America Cordillera began in the late Triassic 210 m.y. ago and ended in the Late Cretaceous 80 m.y. ago. Emplacement of granitic rocks, according to recent studies by J. F. Evernden and R. W. Kistler (r0439), was apparently not continuous but was accomplished during five major epochs of intrusion at approximately 30-m.y. intervals, each epoch taking 10 to 20 m.y. to complete. A progressive transgression of epicontinental seas onto the midcon-

<sup>67</sup> Taubeneck, W. H., and Poldervaart, Arie, 1960, Geology of the Elkhorn Mountains, northeastern Oregon, pt. 2. Willow Lake intrusion: Geol. Soc. America Bull., v. 71, p. 1295–1322.

continent occurred during the same interval of time as the batholithic emplacement to the west. A correlative penecontemporaneous deformation near the loci of granitic emplacement, and a temporary regression during the major progressive transgression of seas onto the midcontinent, took place during each of the five intrusive epochs. The locus of Mesozoic granitic rocks was a source of sediments during most of the period of time that was required to emplace the batholiths, and the origin of the batholithic magmas must be related to other factors in addition to localized downwarping of geosynclines. Strontium isotope data indicate that the source of a significant part of the Sierra Nevada magma was within the mantle. The geologic pattern described above, as well as geochemical and geophysical data from the same region, may be related to northwestward drift of the North America Cordillera onto a Mesozoic oceanic rise according to studies of R. W. Kistler, J. F. Evernden, and H. R. Shaw.

#### **Tidal energy is key to magma production**

H. R. Shaw developed a hypothesis to explain correlations of orogenic with epeirogenic rhythms recently suggested by geochronological studies of J. F. Evernden and R. W. Kistler (r0439). The hypothesis is based on the idea of a mechanical heat engine operated by tidal energy. The mechanical energy is deposited in the earth in the form of magma production by means of a melting mechanism proposed by Shaw (r1542). The coupling of tidal energy and magma production accounts for periodic pulses of magma invasion into continental crust from subcrustal sources. The timing of magma production and intrusion relates periodic cycles of crustal igneous activity to periodic cycles of inflation and deflation of major continental areas. These cycles are somewhat analogous to short-period deformation cycles such as those at Kilauea that were described by R. S. Fiske and W. T. Kinoshita (r0716). Local concentrations of igneous activity in the continental crust relate to concentrations of mechanical energy in the subcrustal source. The hypothesis explains (1) the periodicity of plutonic epochs in the Sierra Nevada during the Mesozoic, (2) oscillations in the eustatic curve during the Mesozoic, and (3) rates of magma production derived from a tidal energy source.

See related study by Shaw on page A112 in the section "Crust and Mantle Studies."

#### **Distribution of scandium between coexisting biotite and hornblende**

Scandium analyses of more than 90 pairs of coexisting biotite and hornblende from igneous rocks of vari-

ous provinces (including the Southern California, Boulder, Sierra Nevada, and Boulder Creek batholiths, and the Jemez Mountains volcanic rocks) indicate that the distribution ratio ( $K_d = Sc_{\text{hornblende}}/Sc_{\text{biotite}}$ ) for most samples closely approaches that of an equilibrium distribution, according to studies by R. I. Tilling, L. P. Greenland, and David Gottfried.<sup>68</sup> Median  $K_d$  values for the igneous samples range from 4.8 to 8.0, which are higher than similar values derived from published data on metamorphic samples and apparently not related to the mode of crystallization (volcanic, hypabyssal, or plutonic). A correlation between  $K_d$  and mafic index,  $(FeO + Fe_2O_3)/(Fe_2O_3 + MgO) \times 100$ , of both the minerals and the host rock, and between  $K_d$  and  $SiO_2$  content of the host rock, can be established only for the Southern California batholith samples. However, whether this correlation reflects temperature dependence, compositional dependence, or both, cannot be specified uniquely with present data. The present data cast doubt on the validity of the so-called scandium geothermometer.

#### **Relation of chromite resources to ultramafic complexes**

A review of world chromite resources by T. P. Thayer (r0995) showed that all the major economic deposits occur in stratiform ultramafic complexes more than 2.5 b.y. old or in alpine complexes of Phanerozoic age, less than 0.5 b.y. old. Podiform deposits have been found in 3-b.y.-old peridotites in South Africa, and in 1.2-b.y.-old peridotites in Goias, Brazil, but individual deposits have yielded only a few hundred tons. Wide disparities in age, magmatic trends, and provenance of the major chromite-bearing peridotites and related feldspathic rocks imply, as Norman Herz<sup>69</sup> suggested with respect to anorthosites, that they were emplaced only at certain stages in earth history.

Textural similarities in stratiform and podiform chromite segregations indicate that they and their host rocks were formed as cumulates. Some unique textures and consistent compositional differences from the stratiform chromitites, however, indicate that the podiform deposits, their alpine-type host peridotites, and related feldspathic rocks crystallized in the upper mantle. The essential restriction of such deposits to Phanerozoic rocks implies progressive differentiation in the upper mantle, changes in mechanisms which move ultramafic rocks into crustal environments, or combinations of the two. Recent descriptions by Thayer (r0094) of rocks dredged from midoceanic ridges sup-

<sup>68</sup> Tilling, R. I., Greenland, L. P., and Gottfried, David, 1969, Distribution of scandium between coexisting biotite and hornblende in igneous rocks: *Geol. Soc. America Bull.*, v. 80, p. 651-688.

<sup>69</sup> Herz, Norman, 1969, Anorthosite belts, continental drift, and the anorthosite event: *Science*, v. 164, p. 944-947.



port the view that gabbroic and trondhjemitic rocks as well as peridotite were formed in the mantle.

#### **Two-magma series in the Boulder batholith**

Study by R. I. Tilling of chemical data from the Boulder batholith, Montana, suggested the possible existence of two contemporaneous (but compositionally distinct) magma series rather than a single (but isotopically complex) magma series. A "potassic" series makes up about 80 percent of the exposed batholith and the remaining outcrops, almost exclusively in the southern end of the batholith, are part of a "sodic" series. The rocks of the sodic series commonly have  $K_2O-Na_2O$  ratios of less than one in contrast to ratios higher than one in the potassic series for a given  $SiO_2$  content. Variations in the lead and strontium isotope ratios and in the thorium and uranium abundances can better be related to the two-magmas-series model.

#### **Cyclic "sedimentation" in ultramafic complexes**

E. D. Jackson<sup>70</sup> pointed out that the lower, ultramafic parts of the Stillwater Complex, Montana, and the Muskox intrusion in Canada are composed of stacks of cyclic units in which the cumulus phases are repeated in a regular order. The successions of cumulus phases in any one cyclic unit are found to correspond to liquidus mineral sequences in experimentally determined simplified basalt systems. Stacks of successively higher cyclic units tend to begin with progressively lower temperature cumulus phases, to contain more iron-rich minerals, and to gradually become thinner upward in the section. Chromite cumulates are an early and integral part of the cyclic units in both intrusions, and, in the Stillwater Complex, platinum-group metals are concentrated in the chromitites. Study of the published descriptions of the Great Dyke and Bushveld Complexes in Africa suggests that similar cyclic units may be present in their ultramafic sections. If this is so, then the similar mechanisms of interrupted fractionation must have operated to form the major style of layering in the four complexes. In addition, the character of the cyclic units indicates some differences in original magma compositions among the four intrusions.

#### **Rare-earth fractionation in alkalic wallrock alteration zones**

The partition of rare earths was found by George Phair and N. L. Hickling to reflect changes in the

bulk composition of alteration zones in the Wet Mountains thorium district, Colorado. Potassic zones made up of nearly pure potash feldspar form the core of replacements of granitic rocks and related gneisses poor in  $CaO$  and  $MgO$ . Marginal to the potassic zones are sodic zones that contain much of the  $Na_2O$  that was leached out of the granitic and gneissic rocks during its replacement by potash feldspar.

The potassic inner zone is characterized by yttrium (up to 0.13 percent) in marked excess over cerium plus lanthanum. In the sodic marginal zones cerium and (or) lanthanum range up to 0.07 percent and are about twice as plentiful as yttrium; hence, the order of abundance of these elements is reversed from that in the potassic zones.

Thorium-rich ore segregations, in fissures which are closely associated with the potash feldspar alteration zones, are characterized by concentrations of samarium, gadolinium, and neodymium, equal to, or greater than, those of yttrium, cerium, and lanthanum. Concentrations as high as 0.1 percent Sm and 0.3 percent Gd in thorite ores, and 0.5 percent Nd in thorite-brookite ores, are most unusual natural concentrations for these relatively scarce rare-earth elements.

### **METAMORPHIC ROCKS AND PROCESSES**

#### **Age of blueschist metamorphism in southwestern Oregon**

R. G. Coleman, M. A. Lanphere, and Z. E. Peterman concluded that the Colebrooke Schist nappes of southwestern Oregon have been emplaced by westward thrusting. Serpentinite sheets formed during westward thrusting and tectonic transport contain numerous exotic blocks of igneous and metamorphic rocks. Metamorphic grade of the Colebrooke Schist is intermediate between blueschist and greenschist facies and developed before thrusting. Rb-Sr whole-rock age for the Colebrooke Schist is approximately 130 m.y. High-grade blueschist exotic blocks transported within the underlying serpentinite sheets give K-Ar ages on phengitic micas of 150 m.y. Tectonic juxtapositioning of low- and high-grade blueschists of Oregon follows the same pattern of ages found in the tectonic mixed blueschist of California. The wide distribution of 150-m.y. high-grade blueschist exotic blocks from Roseburg, Oreg., southward to southern California suggests that there exists along the continental edge an extensive but cryptic belt of blueschists. The close association of the exotic blocks in serpentinite suggests that the blueschists may have been associated with peridotites at greater depths and tectonically transported into the crust at a time when an oceanic

<sup>70</sup> Jackson, E. D., 1970, The cyclic unit in layered intrusions—A comparison of repetitive stratigraphy in the Stillwater, Muskox, Great Dyke, and Bushveld Complexes: South Africa Geol. Soc. Spec. Paper 1. [In press]

plate was impinging against the eastern Pacific continental plate.

#### **Deformation and metamorphism in the northern Sierra Nevada foothills belt**

Anna Hietanen recognized two episodes of deformation and metamorphism in the Bucks Lake quadrangle, California. During the first episode, the rocks were folded isoclinally, and acquired a pronounced foliation parallel to the axial planes. The recrystallization was at temperatures and pressures characteristic of the greenschist facies. A second folding and recrystallization took place during the emplacement of the Early Cretaceous plutons and under temperatures and pressures characteristic of the epidote amphibolite facies. Typical assemblages include biotite-muscovite-staurolite-andalusite and biotite-muscovite-cordierite-andalusite. Serpentinization of the ultramafic bodies was intimately associated with the metamorphic events. The amount of available H<sub>2</sub>O controlled the degree of serpentinization. Ultramafic rocks and the enclosing metasediments exchanged components in a closed system.

#### **Pumpellyite from Bunker Hill, southeastern Pennsylvania**

E-an Zen discovered pumpellyite in altered mafic volcanic rocks from Bunker Hill near Jonestown, southeastern Pennsylvania. The rocks are from the so-called Jonestown volcanics, a group of isolated volcanic rocks in the Middle to Upper Ordovician Martinsburg Formation. The rocks may be exotic blocks. Pumpellyite occurs as pseudomorphs after pyroxene phenocrysts and as vug fillings or linings. The presence of pumpellyite suggests low-grade metamorphism of the rocks, a fact hitherto not realized. It is possible that prehnite-pumpellyite grade of metamorphism is more widespread on the low-grade western flank of the Appalachians than has been realized. Pumpellyite optically resembles chlorite; its presence could have escaped notice in many rocks. The presence of pumpellyite in the Jonestown volcanics indicates the possibility that the physicochemical control of metamorphism leading to the formation of pumpellyite-prehnite facies could be clarified here by careful sampling and petrographic work.

### **SEDIMENTARY ROCKS AND DIAGENETIC PROCESSES**

#### **Sedimentary zeolites**

K. J. Murata reported that the irregular distribution of laumontite in the Miocene Briones Sandstone of California is caused by two factors: (1) calcite in calcite-rich beds seals the layer against solutions

which tend to promote laumontite growth, and (2) noncalcareous beds do not have laumontite for lack of calcium. J. D. Vine (r0314) observed laumontite in arkosic sandstones in the Spanish Peaks area of southern Colorado; the sandstones belong to the early Eocene Cuchara and Huerfano Formations, the Upper Cretaceous and Paleocene Poison Canyon Formation, and the Pennsylvanian and Permian Sangre de Cristo Formation. In an area of 450 sq mi laumontite occurs as cement and as replacement of potassic feldspar, making up as much as 25 percent of the rocks. The laumontite fits into a zonal arrangement of secondary minerals surrounding the Spanish Peaks intrusive rocks, with epidote nearest each intrusive, laumontite next, and montmorillonite in the outer part. Other authigenic minerals include hematite, analcime, calcite, sericite, and kaolinite. Vine and E. B. Tourtelot noted that many lower Eocene sandstones from other basins show similar alteration pattern and secondary minerals; the pattern observed for the Spanish Peaks area may be applicable to these other basins where the alteration is associated with uranium deposits.

R. A. Sheppard and A. J. Gude III studied phillipsite from cored and dredged samples taken by the Scripps Institution of Oceanography from deep parts of the Pacific and Indian Oceans. They found that these phillipsites have higher Si-Al ratios (2.4-2.8) relative to phillipsites from mafic igneous rocks (1.3-2.4) and K-Na ratios greater than unity. In contrast to published analyses, these deep-sea phillipsites are relatively low in barium, generally less than 0.3 wt percent.

H. C. Starkey, in cooperation with A. O. Shepard, determined that in ion-exchange experiments using clinoptilolite from the Pierre Shale, lithium enters the structure only after the mineral was first ion exchanged with sodium. They also found that, for both clinoptilolite and heulandite, the radius of the exchangeable ion in the structure affects the stability of the mineral upon heat treatment: Larger ions such as potassium prevent breakdown of the mineral. High Si-Al ratio appears to have the same effect and could compensate for low potassium content.

#### **Green River mineralogy**

The oil shales of the Parachute Creek Member of the Eocene Green River Formation in the Piceance Basin, northwest Colorado, form a laminated sequence of light and dark beds. D. A. Brobst determined that these beds consist mainly of dolomite, calcite, quartz, and varying amounts of alkali feldspars, analcime, clay minerals, pyrite, dawsonite and other saline min-

erals, as well as oily substances (kerogen). Brobst concluded from preliminary results of X-ray diffraction studies of about 300 samples from beds and groups of laminae that variations in mineral content from layer to layer may be as much as tenfold. Similar magnitude of variation exists for a given layer over distances of a few hundred feet laterally.

By studying various drill cores from the Green River Formation donated by companies, Charles Milton found that nahcolite in the Piceance Basin occurs as fine rosettes of crystals associated with searlsite, as well as crystalline masses. In the Washakie Basin of Wyoming, labuntsovite in scanty amounts is commonly associated with trona; strontianite and natron-catapleite, both new for the Green River Formation, are also present. A core from the Uinta Basin of Utah contains a hydrocarbon having metallic luster and high nickel content in the ash; it also contains an authigenic mica which may be hydrobiotite, another first for the Green River Formation.

#### Gold in aqueous solutions

Peter Zubovic found that, in the presence of humic acid, ionic gold reduces to form a colloidal complex. The size of colloid particles in the complex varies directly with the pH of the system. At pH values in excess of about 8.6, some gold remains ionic. Infrared study indicates some oxidation of organic matter as a result of gold reduction.

#### Statistical interpretation of paleocurrent and paleoslope data

C. A. Wallace found that circular normal statistics,<sup>71</sup> although less efficient and less powerful than conventional Student's *t* or *F* statistics, is useful for the analysis of paleocurrent and paleoslope data because these data may be distributed over a range of 360° and thus are not amenable to analysis by the linear Student's *t* or *F* tests. Use of the circular normal statistics on 4,500 paleocurrent and paleoslope measurements from the Precambrian Uinta Mountain Group, Uinta Mountains, Utah, yielded somewhat different results than estimates and comparisons based on the Student's *t* or *F* statistics; these differences can be critical to statistical and geologic interpretation of the data.

#### Stratigraphic geochemistry of apatite

According to D. R. Lowe, the late Miocene upper Sespe Creek phosphate deposit in northwestern Ven-

tura County, Calif., shows systematic changes of content of structural CO<sub>2</sub> in the carbonate/fluorapatite, depending on stratigraphic position. The study, based on X-ray diffraction determination of cell dimensions, shows variation in CO<sub>2</sub> from 1 to 4 percent. CO<sub>2</sub> in the apatite decreases upward from the base to the middle of the phosphate member, then increases to the top. Lateral variations in CO<sub>2</sub> within individual beds appear to depend on local tectonic history and proximity of inferred shorelines. The CO<sub>2</sub> variation is interpreted to reflect variations in CO<sub>2</sub> availability in local sea water during phosphate deposition; freshwater masses supply CO<sub>2</sub> in nearshore areas, whereas cooler water and lowered pH, perhaps related to water depth, in offshore areas decrease the available CO<sub>2</sub>.

### DISTRIBUTION OF ELEMENTS

#### Biogeochemistry of gold

H. T. Shacklette, H. W. Lakin, A. E. Hubert, and G. C. Curtin (r2477) conducted experiments on the chemical behavior of gold in plants. Rooted plants and unrooted cuttings of impatiens (*Impatiens holstii*) and garden balsam (*I. balsamina*) did not absorb through roots, or absorb and transport through cut stems, gold sols reduced by glucose or sodium oxalate that contained Au<sup>198</sup>, as shown by leaf autoradiographs. Radioactive gold from a chloride solution was not found in leaves of rooted impatiens plants, but was found in leaves of unrooted cuttings even though some of the gold was precipitated as a blue coating of colloidal gold on the cut surfaces and in vascular cells. Leaf autoradiographs showed that Au<sup>198</sup> in solutions of gold cyanide, bromide, iodide, and thiocyanate was absorbed by both rooted plants and unrooted cuttings, but that more was absorbed by the unrooted cuttings. The concentrations used produced necrosis of the plants. Rooted plants in more dilute Au<sup>198</sup>CN absorbed radioactive gold and transported it to the leaves while the plants produced new root growth and flowers. Radioactive gold in a thiosulfate solution was not absorbed by rooted plants, but large amounts were absorbed by unrooted cuttings. Radioactive gold solubilized by an extract from flax plants that contained HCN derived by enzymatic action from a natural glycoside was absorbed in greater amounts by rooted plants than by unrooted cuttings.

Atomic absorption analyses of stems and leaves of these plants showed that nonradioactive gold (Au<sup>197</sup>) chloride, cyanide, bromide, iodide, and thiosulfate were readily absorbed by both rooted plants and unrooted cuttings. Of these compounds, gold cyanide was

<sup>71</sup> Jones, T. A., 1968, Statistical analysis of orientation data: Jour. Sed. Petrology, v. 38, no. 1, p. 61-67.

Batschelet, E., 1965, Statistical method for the analysis of problems in animal orientation and certain biological rhythms: Am. Inst. Biol. Sciences, Washington, D.C., 57 p.

absorbed in the largest amounts and comprised as much as 320 ppm of the dry weight of the plant.

Roots of onion (*Allium cepa*) bulbs readily precipitated colloidal gold from solutions of gold chloride and gold bromide. Roots of this plant were able to grow in length in dilute gold cyanide solutions.

Of the solutions tested, gold cyanide was the most readily absorbed by roots and transported in largest amounts to leaves. If gold is present in the soil, and if cyanogenetic plants are rooted in this soil, a mechanism is present for the entrance of gold into the biogeochemical cycling process.

Three gold-bearing samples of mull (forest humus layer) were leached with demineralized water by G. C. Curtin, H. W. Lakin, and A. E. Hubert (p. C127-C129). The leachate from the first sample was passed through an  $0.45\mu$  average pore diameter membrane filter. The remaining two leachates were passed through  $0.05\mu$  average pore diameter membrane filters. The filtered leachates contained 110, 27, and 120 ppt ( $1 \times 10^{-12}$ ) Au respectively. The lowest gold content occurred in a leachate that was straw-yellow, whereas the two high gold contents occurred in leachates that were light to dark brown suggesting a positive correlation of gold content with density of color of the leachates. Because dissolved organic compounds probably are the primary coloring agents in the solutions, the gold may be present either as a gold-organic complex ion or as an organic-protected colloid.

The gold in the mull probably reflects a biogeochemical cycle in which gold is leached from the bedrock, is absorbed by vegetation, and is concentrated in the mull as the vegetation decays. In the relatively dry, aerated surface layer of the mull a biogeochemical process may take place in which cyanide and thiocyanate ions, which are products of hydrolysis of plant glycosides by enzymatic action, are produced during decay of vegetation and these ions, in turn, form stable, water-soluble gold complexes. The gold in the reducing environment of the well-packed, water-soaked mull beneath the relatively dry surface layer, however, probably is in the colloidal state and may reflect the release of gold from decaying vegetation either as extremely small colloidal particles or as ionic gold which is subsequently reduced to the colloidal state.

Gold in the form of extremely small colloidal particles ( $<0.05\mu$  diameter) is probably the principal source of gold in the leachates, and gold cyanide and gold thiocyanate ions may be present in minor amounts.

### Background geochemistry of soils of the United States

Samples of surficial materials, largely soils, from 863 sites almost evenly distributed over the conterminous United States have been collected and analyzed for 35 elements. A report<sup>72</sup> by H. T. Shacklette, J. C. Hamilton, J. G. Boerngen, and J. M. Bowles contains maps showing regional variations of element concentrations, frequency distributions, and measures of average and of variation. Surficial materials from the western half of the United States generally contain more calcium, magnesium, strontium, potassium, sodium, aluminum, and barium, and less titanium and zirconium than do those of the eastern half. Surficial materials in the Atlantic and Gulf coastal plains tend to have much lower concentrations of most metals than is common in those of other regions, whereas these materials in the Basin and Range province, the Rocky Mountains, and the northern New England States generally have high metal concentrations.

### Minor elements in black shales

Chemical analyses from 20 representative sets of black-shale samples were used by J. D. Vine and E. B. Tourtelot to estimate the composition of "average" black shale, to define the minimum concentration of each of 21 minor elements required to describe a sample as metal rich, and to compare the association of minor elements with major rock constituents in each of the 20 sets. The "average" and "enriched" values (in parentheses) are as follows: Ti 0.2 (0.7), Mn 0.015 (0.1), Ag 0.0001 (0.0007), B 0.005 (0.02), Ba 0.03 (0.1), Be 0.0001 (0.0003), Co 0.001 (0.003), Cr 0.01 (0.07), Cu 0.007 (0.02), Ga 0.002 (0.005), La 0.003 (0.007), Mo 0.001 (0.02), Ni 0.005 (0.03), Pb 0.002 (0.01), Sc 0.001 (0.003), Sr 0.02 (0.15), V 0.015 (0.1), Y 0.003 (0.007), Zn 0.03 (0.15), Zr 0.007 (0.02), and U 0.001 (0.003). "Average" black shale was calculated as the median of the 20 set medians, giving equal weight to each sample set, whereas the "enriched" values correspond approximately to the 90th percentile. The association of minor elements with major rock constituents is uniquely different for each set, but the following more mobile elements were found to be associated with organic matter in one or more sets: Co, Cu, Cr, La, Pb, Mo, Ni, Se, Th, U, V, Y, and Zn.

### Geochemical discrimination among crude oils

J. J. Connor and P. M. Gerrild reported that stepwise multiple discriminant-function analysis of the

<sup>72</sup> Shacklette, H. T., Hamilton, J. C., Boerngen, J. G., and Bowles, J. M., 1971. Element content of surficial materials in the conterminous United States: U.S. Geol. Survey Prof. Paper 574-D. [In press]

geochemistry of 57 crude-oil samples from 6 closely spaced Pliocene sandstone reservoirs in the Elk Hills field, California has resulted in discriminant functions capable of correctly assigning 77 percent of the samples to their proper stratigraphic position. The functions consist of weighted linear combinations of five measurements of hydrocarbon fractions and four elements—V, Fe, Be, and Co—in ash. Furthermore, these functions clearly indicate that the crude oils from the six sandstones consist of three distinct compositional types. These types may reflect natural fractionation from a common indigenous parent oil.

#### **Geochemical discrimination among volcanic ash layers**

Some of the volcanic ash layers that occur throughout the Western United States have proved to be useful time-stratigraphic markers. This use will be extended when more definitive correlations among the ashes have been established. The subject is being investigated by G. A. Borchardt, P. J. Aruscavage, H. T. Millard, Jr., G. A. Izett, and R. E. Wilcox. Instrumental neutron-activation analysis was used to measure 23 elements in samples of Bishop ash from 7 locations in California, Utah, Colorado, and Nebraska; 2 samples of Bishop Tuff from California; 3 samples of "Bishop-like" ash; and 14 samples of "Pearlette" Ash from Utah, Colorado, Kansas, and Nebraska. The analytical data, when treated statistically by discriminate-function analysis, indicated that Sm, Th, Sc, Hf, Mn, Eu, Dy, Sb, and Na were the more useful elements for classifying these ashes, whereas K, Rb, Cs, Lu, La, Ce, Zr, Ta, Ba, Th, Yb, Co, Fe, and Cr were less useful. The Bishop ash could easily be distinguished from "Bishop-like" and Pearlette ashes. The three "Bishop-like" ashes, although physically similar to the Bishop Tuff, were shown to be chemically distinct.

### **GEOCHEMISTRY OF WATER**

The primary objectives of geochemical studies in hydrology are (1) to understand the hydrochemical processes that control the chemical character of water, (2) to increase understanding of the physics of the flow system by application of geochemical principles, and (3) to understand the rates of chemical reactions and rates of transport of physical and chemical masses within the hydrologic system.

#### **PRECIPITATION, SURFACE-WATER, AND GROUND-WATER STUDIES**

##### **Precipitation contribution to ground-water quality**

Ions supplied by precipitation appear to provide the major controls on the chemistry of Long Island

ground water. F. J. Pearson, Jr., and D. W. Fisher found that concentrations of calcium, magnesium, potassium, and chloride in water from the Magothy aquifer, Long Island, N.Y., are approximately the same as corresponding concentrations in Long Island precipitation (after taking evapotranspiration into account). Sodium concentration in the ground water is higher than average sodium levels in precipitation; however, the difference can be attributed to an exchange reaction between aluminosilicate minerals and hydrogen ion from the precipitation. The concentration of sulfate in water from the Magothy is much less than would be expected on the basis of composition of modern rainfall. However, sulfate concentration in water from a shallow aquifer above the Magothy aquifer corresponds quite well with the average sulfate level in precipitation. The different ground-water sulfate concentrations may well be a result of differences in average composition of the recharge water. The relatively fast-moving water in the shallow aquifer probably responds rapidly to changes in composition of the recharge water, whereas water in the much larger Magothy aquifer is a composite of old and new recharge water, with a composition more nearly representative of old precipitation in which sulfate produced by the burning of fossil fuels is absent.

##### **Chloride in stream water**

Chloride, a major constituent of sea water, is recycled to land from the oceans as a constituent of aerosols. The chloride reaches the land surface as dry fallout or is carried down by atmospheric precipitation. In coastal areas, significant amounts of chloride may accumulate at the land surface during a dry season and be available for removal by runoff during the first rainfall. However, a large flushout of chloride has not been observed in a detailed study by V. C. Kennedy of the Mattole River in northern California. Instead, analyses of soil samples collected from various depths after early fall rains suggest that much of the surface chloride is carried into the soil by rainfall before surface runoff occurs. A part of this chloride may appear in subsurface runoff during and after early rains, but much of it percolates downward and is released slowly to the streams.

##### **Quality of ground water in the Red River of the North drainage basin in Minnesota**

A recently completed study of the Red River of the North drainage basin in Minnesota (about 17,000 sq mi) by R. W. Maclay, T. C. Winter, and L. E. Bidwell included a regional synthesis of ground-water

quality. Dissolved-solids content ranges from about 300 mg/l to more than 2,000 mg/l. The most common values are between 300 and 600 mg/l. Most of the ground water is hard, ranging from about 200 to 400 mg/l. The water types, mapped on a fence diagram of the basin, show a close relationship to geologic environment and ground-water movement. Some mixing of water types occurs where calcium-magnesium-bicarbonate or calcium-magnesium-sulfate water in the glacial drift comes in contact with sodium-bicarbonate or sodium-chloride water moving upward from the underlying Cretaceous and Paleozoic sedimentary rocks.

#### **Abert Lake, Oreg.**

A study by B. F. Jones, A. H. Truesdell, and Nobuhiro Yotsukura at Abert Lake, Oreg., of geochemical and hydraulic features of the Chewaucan River "estuary" demonstrated marked stratification. Distribution of chloride was used to delineate convective diffusion mechanisms, including movement upstream of the bottom saline water. Much of the chemical composition of the water bodies can be explained by a simple mixing model.

Jones described a procedural scheme for chemical pretreatment and centrifugal separation which was employed for analysis of submicron-size lacustrine sediment from Abert Lake. X-ray diffractometer and powder camera data coupled with replicate analyses of solids and extractant solutions indicated that the material is composed principally of a siliceous montmorillonite with a Mg-Fe ratio of about 2:1 and a coating of amorphous silica containing significant amounts of sorbed magnesium.

#### **Nonmineral carbonate dissolved in ground water**

The carbonate species dissolved in water from the Magothy aquifer, Long Island, N.Y., were studied by F. J. Pearson, Jr., and Irving Friedman. This aquifer is nearly free of carbonate minerals and contains water whose chemistry is controlled by the chemistry of atmospheric precipitation. Wells near the recharge area have stable carbon isotope ratios like those of plants ( $\delta C^{13} \approx -25$  per mil) and total carbonate contents corresponding to a  $CO_2$  partial pressure of about  $4 \times 10^{-3}$  atm. This shows that the carbonate here is derived from the soil zone. Downgradient, the total carbonate doubles, but the carbon isotope ratios remain close to those of plants ( $\delta C^{13}$  more negative than  $-18$  per mil). The increase of dissolved carbonate is due in part to solution of carbonate mineral, but largely results from oxidation of lignite in the aquifer by oxygen dissolved in the water.

#### **Radiocarbon concentration related to occurrence of salt water in coastal aquifers**

Continuation of the study of carbon-14 and chloride concentrations in ground water in the vicinity of Hilton Head Island, S.C., by William Back, B. B. Hanshaw, and Meyer Rubin indicated that the source of salt water at the northern end of the study area is modern ocean water and that the source of contamination near the center of the island is saline formation water. Under native conditions, the original regional flow path was northeastward (generally from the south end to the north end of the island). At the south end, the fresh water (less than 35 mg/l Cl) is older than 22,000 years. In the central and higher part of the island, the age of the fresh water ranges from about 2,000 to 12,000 years. This age range is interpreted to mean that with a lowering of regional head, owing to heavy pumping in the Savannah, Ga., area, regional flow has reversed, and recharge is being induced into the aquifer in this area. In the central part of the island, the deeper contaminated zone (chloride content about 1,500 mg/l) has an age of about 26,000 years. In the northern part of the island, water of the same chloride content has an age of about 7,000 years. In this study, therefore, chloride and carbon-14 concentrations show the effects of (1) reversal of flow, (2) area of resultant recharge, (3) area of modern ocean-water encroachment, and (4) area of contamination by saline formation water.

#### **Quality of ground water of the Columbia River basalt**

A compilation of 525 comprehensive analyses on ground water in the 50,000-sq-mi area of layered basalt showed the water to be a rather uniform bicarbonate type with calcium and sodium nearly equal as the principal cations. The prevalent ground water contains an average of 55 mg/l Si, 0.2 mg/l Fe, 34 mg/l Ca, 13 mg/l Mg, 37 mg/l Na, 7 mg/l K, 150 mg/l  $HCO_3$ , 20 mg/l  $SO_4$ , 10 mg/l Cl, and 0.5 mg/l F. It has moderate hardness and a pH of 7.8. Sodium-bicarbonate water is most common beneath the floors of main synclinal valleys, and calcium-bicarbonate water is most common elsewhere.

Special types of native ground water form only a minor part of the ground water and are of the following four classes: (1) calcium-sodium-chloride water that rises from underlying sedimentary rocks west of the Cascade Range; (2) mineralized water at or near warm or hot springs; (3) water with unusual concentrations of ions, especially chloride, near sedimentary rocks intercalated at the edges of the basalt; and (4) more mineralized water with excess carbon dioxide at one locality. One special class of ground water,

relatively high in salt content, has resulted from unintentional artificial recharge owing to escape of irrigation water in places in central Washington.

Radioactivity of the ground water is low. Determinations showed that minor elements, of possible deleterious effect, are lacking or only present in safe and minute amounts. Carbon-14 age determinations showed that the ground water ranges from modern to older than 32,000 years. A general correlation exists between depth and age of the ground water.

### CHEMICAL-EQUILIBRIUM AND KINETICS STUDIES

#### Florida and Yucatan carbonate aquifers

In a continuing study of carbonate aquifer systems, B. B. Hanshaw, William Back, and R. G. Deike found that Tertiary limestone of the principal artesian aquifer of Florida is composed primarily of calcite and dolomite with minor amounts of quartz and apatite, and that the magnesium content of the calcite is slightly lower (0–2 percent  $\text{MgCO}_3$ ) in the recharge areas than in the deeper, confined parts of the aquifer system (2–4 percent  $\text{MgCO}_3$ ).

The Mg-Ca ratio in water from the aquifer is as low as 0.05 in the recharge area where the water is undersaturated with respect to both calcite and dolomite. With time and length of travel path in the system, the water increases systematically in Mg-Ca ratio, which approaches unity; saturation with respect to the two carbonates also increases downgradient until the solution becomes oversaturated with respect to both carbonates. In Tertiary limestones of the Yucatan Peninsula, the Mg-Ca range in water is similar to that for Florida.

The small amount of magnesium available from the solution of magnesium calcites and dolomite in the potable zone of active circulation is insufficient to provide the amount required for extensive dolomitization unless enormous quantities of rock are available for dissolution. However, dolomite may be forming in the zones of brackish water that underlie the Florida and Yucatan Peninsulas. The required magnesium may be derived from the readily available ocean water or reflux brines as the hydrologic regimen is changed because of relative fluctuations of sea level.

#### Rates of processes in natural systems

William Back and B. B. Hanshaw reported that for much of the Tertiary carbonate aquifer system of Florida, the velocity of ground-water flow ranges from 2 to 15 m/yr. As the water moves downgradient, it attains equilibrium with respect to calcite at about 3,000 carbon-14 years and with respect to dolomite in about 15,000 carbon-14 years.

A general reference base for irreversible processes is provided by entropy production which serves as the unifying concept that relates the physical and chemical processes. The rate of entropy production from the dissolution of calcite and dolomite is calculated from thermodynamic properties of the minerals as a function of flow rate and molal activity of ground-water solutions. In addition, the rate of entropy production was estimated for the irreversible processes of water movement down the potentiometric gradient. Combining the amount of entropy produced from the chemical and physical processes with carbon-14 ages provides an approximation of the total entropy production for the system as a function of time and distance. Distribution of entropy production provides an integrating variable for use in evaluating the relative importance of physical and chemical processes at points within a system or between two hydrologic systems.

In studying crystallographic controls on rates of chemical reactions, Ivan Barnes' studies of calcite and dolomite from stream-bed conglomerates in the coastal ranges of California showed that calcite has a compositional range of  $\text{CaCO}_3$  to  $\text{Ca}_{0.5}\text{Mg}_{0.5}\text{CO}_3$ . Calcite is characterized by a lack of the {015} ordering X-ray diffraction maximum over the entire composition range. The basal repeat {006} is only found for calcite near  $\text{CaCO}_3$  in composition. Dolomite is the phase that yields both the {015} and {006} X-ray diffraction maximums over its entire composition range, which is at least from  $\text{Ca}_{0.6}\text{Mg}_{0.4}\text{CO}_3$  to  $\text{Ca}_{0.5}\text{Mg}_{0.5}\text{CO}_3$ . Dissolution rates of dolomites of all compositions are markedly slower than calcites of all compositions. The rate studies were made using dilute HCl. Qualitative results using  $\text{H}_3\text{PO}_4$  are similar.

#### Computer program for equilibrium studies

B. F. Jones and A. H. Truesdell developed a computer program to model the distribution of solute species from the analysis of natural water and to evaluate saturation with associated minerals. The chemical state of the water is described by mass-action equations using association constants from experimental or thermochemical data. Single-ion activity coefficients are calculated from an extended Debye-Hückel equation with parameters for major ions chosen to agree with coefficients derived from the McInnes assumption. Ion activity products obtained from the recalculated analysis are then compared with equilibrium constants for appropriate minerals. Attempts have been made to include aluminosilicates, fluoride, and phosphates. The format is arranged to



facilitate the substitution of new data or specific values preferred by the user.

#### Silver adsorption by manganese oxides

A study of the adsorption of silver by manganese oxides was made by B. J. Anderson, E. A. Jenne, and T. T. Chao as part of a program on the mechanism of transport of silver in fluvial media. Four manganese oxide preparations were synthesized and equilibrated with silver solutions of different concentrations at varying pH levels. The amount of silver adsorbed increased with both increasing pH and silver concentration. The total silver adsorbed was in the range of 0.1 to 0.5 moles per mole of manganese oxide and varied with the type of manganese oxide. The data relating the amount of silver adsorption to silver concentration may be plotted according to the Langmuir equation. The relatively great amount of adsorption is explained in terms of surface retention and the formation of a silver manganite from sodium or potassium manganous manganite as a derivative of the manganese oxide structure. It is expected that silver will be preferentially adsorbed by manganese oxides and transported as part of the suspended load of streams and rivers.

#### Geothermal systems

Vapor-dominated ("dry-steam") geothermal systems are scarce and poorly understood compared to hot-water systems. Critical physical data on both types were obtained by D. E. White, A. H. Truesdell, L. J. P. Muffler, and R. O. Fournier from research drilling in Yellowstone National Park. Vapor-dominated systems require potent heat supplies and low permeability. After an early hot-water stage, a system becomes vapor dominated if net discharge exceeds recharge. Steam boils from a declining water table; some steam escapes but most condenses near the surface, where its heat of vaporization can be conducted into the surrounding rock. The "steam" reservoir is an efficient two-phase heat-transfer system. Vapor boiled from the deep (brine?) water table flows upward; liquid condensate flows down. Liquid water favors small pores and channels (high surface tension). Steam dominates the larger channels and discharge from wells. The initial low permeability of water recharge channels becomes even lower because of the decreasing solubility of carbonates and  $\text{CaSO}_4$  with temperatures. The "lid" on the system is argillic-altered rocks and  $\text{CO}_2$ -saturated condensate. The model and the thermodynamic properties of steam explain the major vapor-dominated reservoirs of Larderello, Italy, and The Geysers, Calif., where initial temperatures were uni-

formly near  $240^\circ\text{C}$  and pressures near 500 psi. Local pore liquid and the great stored heat of solid phases account for the high steam productivity.

Fournier and Truesdell evaluated geochemical indicators of subsurface temperatures in the hot-spring systems of Yellowstone by comparing aquifer temperatures estimated from compositions of hot-spring waters with measured temperatures in nearby drill holes. The "silica geothermometer" of Fournier and J. J. Rowe<sup>73</sup> was found to be the only reliable temperature indicator where aquifer temperatures are in the approximate range  $120^\circ$  to  $220^\circ\text{C}$ . Where subsurface temperatures exceed  $220^\circ\text{C}$ , the silica geothermometer is likely to give low estimated temperatures owing to precipitation of silica during ascent of the water. The deposition of silica, however, may prevent other solution-wallrock reactions from occurring during ascent of water owing to silica armoring of the channelways. Thus, the ratio  $\text{Na/K}$ , suggested by White<sup>74</sup> and used in conjunction with the silica geothermometer, may give good estimates where subsurface temperatures exceed  $220^\circ\text{C}$ .

The deep drilling and the water chemistry, mentioned above, have shown that all the deep rising water of Yellowstone's geyser basins has a temperature of  $200^\circ\text{C}$  or more. The importance of near-surface convection in dispersing this excess energy was demonstrated by White, who measured vertical temperature profiles in 100 geyser tubes and hot-spring vents. Only 17 of these could be probed to 30 feet or more, and 17 (only 9 are in both lists) had temperatures greater than  $100^\circ\text{C}$ ;  $92^\circ\text{C}$  is boiling for the altitude. Lion Geyser of Upper Basin is the deepest (77 feet) and is also highest in temperature ( $124.2^\circ\text{C}$ ). Large-diameter vents (5 feet or more) tend to be flat floored with high-temperature water entering from the sides or from small downward extensions. The large tubes commonly flare upward into much larger surface pools; they are remarkably effective dispersers of energy, with vigorous convective circulation and commonly with local boiling only near the top of the tube. Morning Glory Pool of Upper Basin is an example of nonboiling convective dispersal; temperature extremes were  $71.6^\circ\text{C}$  at the surface and  $72.8^\circ\text{C}$  at 23 feet. High-temperature inflow was not detected but, from drill-hole data, is likely to be about  $110^\circ\text{C}$  (for 23 feet in depth).

White also found a "hot pot" of natural molten

<sup>73</sup> Fournier, R. O., and Rowe, J. J., 1966, Estimation of underground temperatures from silica content of water from hot springs and wet-steam wells: *Am. Jour. Sci.*, v. 264, p. 685-697.

<sup>74</sup> White, D. E., 1965, Saline waters of sedimentary rocks, in *Fluids in subsurface environments—A symposium*: *Am. Assoc. Petroleum Geologists Mem.* 4, p. 342-366.

sulfur near the accessible bottom of Cinder Pool in the western part of Norris Basin, Yellowstone Park. The origin of the pool's "cinders" has long been a puzzle. Most cinders are black hollow spheres of native sulfur that float on the surface of the pool and are unlike any other sulfur occurrence in the Park. Temperature-depth profiling showed a shallow convection cell from the surface to 30 feet, with temperatures from 85.6° to 87.3°C; a deeper convection cell from 30 to 64 feet had a temperature of 90°±0.5°C except at the bottom, where fluctuations from 90° to 92°C occurred. Further penetration was difficult but was accomplished with the aid of a lead weight on the thermistor cable. An astonishingly high thermal gradient occurs just below 64 feet: 108°C at 64½ feet, 113.5°C at 65 feet, and 117°±0.5°C from 66 to 72 feet. The cable, thermistor probe, and lead weight, upon withdrawal, were found to be coated with congealed vesicular elemental sulfur at all depths below 64 feet. The interface at this depth is evidently molten elemental sulfur that is probably a convecting liquid in the bottom of the pool but is chilled viscous "glass" near its contact with overlying water.

## ISOTOPE AND NUCLEAR GEOCHEMISTRY

### ISOTOPE TRACER STUDIES

#### Strontium isotopes and volcanic rocks

Very little new data have appeared on the strontium isotopic composition of oceanic ridge tholeiites since Tatsumoto, Hedge, and Engel<sup>75</sup> reported that samples from the East Pacific Rise contained the most unradiogenic strontium known on earth. Twelve new samples have now been analyzed by C. E. Hedge and Z. E. Peterman from the Juan de Fuca and Gordo Rises. Their strontium is also very unradiogenic with values of  $\text{Sr}^{87}/\text{Sr}^{86}$  ranging between 0.7012 and 0.7030. New analyses have also been made of tholeiite suites from several islands in the Pacific Ocean Basin. The island basalts are consistently more radiogenic with  $\text{Sr}^{87}/\text{Sr}^{86}$  values of 0.7030 to 0.7055 than the basalts from the active rises of the Pacific Ocean. These data, combined with published results, indicate that variations in Rb/Sr have persisted in the mantle for billions of years. The amount of potassium relative to total alkali elements also correlates with the strontium isotopic composition, suggesting that there are long-term major-element heterogeneities

in the mantle which influence the chemical characteristics of the magmas derived therefrom.

A study of strontium isotopes in circum-Pacific calc-alkaline orogenic andesites is also underway. The  $\text{Sr}^{87}/\text{Sr}^{86}$  values of calc-alkaline rocks erupted along island arcs on oceanic basement (for example, Little Sitkin, Alaska; Izu Islands; Mariana Islands) and in continental areas of relatively thin, young crust (for example, Mount Hood and Tertiary volcanic rocks of western Oregon; Talasea, New Britain; Hakone, Japan) are relatively uniform with an average of about 0.7035. That these values are identical with those of many oceanic basalts implies an upper mantle source with minimal crustal involvement. Similarly, the Tertiary and Quaternary andesites from the Cascade Range of Washington, Oregon, and northern California all have  $\text{Sr}^{87}/\text{Sr}^{86}$  ratios within the range of 0.7030 to 0.7040 with no relation to whether or not a pre-Cenozoic basement is present; this further suggests a subcrustal origin. In areas such as the Chilean Andes or the San Juan Mountains, Colo., where the lavas have erupted through an older continental crust, the rocks have higher and more variable  $\text{Sr}^{87}/\text{Sr}^{86}$  ratios. Even in these areas, however, the amounts of radiogenic strontium are low enough to indicate that the involvement of crustal material is not a controlling factor in the generation of calc-alkaline suites, but only a modifying feature.

#### Geochemical study of Columbia River Basalts

Systematic collections were made from four of the better known sections in the extensive Miocene and Pliocene lava field of Oregon and Washington comprising the Columbia River Basalts. This study, undertaken by Ian McDougall, involved the measurement of the isotopic composition of strontium, and abundances of potassium, rubidium, and strontium in the samples to help explain the origin and history of these lavas. The results show that the basalts in each section sampled possess a characteristic geochemistry with only small variations in composition. However, significant differences, especially in initial  $\text{Sr}^{87}/\text{Sr}^{86}$  ratio, were observed between the four sequences studied in detail. These data indicate that the lavas in a particular sequence have a common origin and history, but that a somewhat different history must be postulated for each sequence compared with the other sequences. The initial  $\text{Sr}^{87}/\text{Sr}^{86}$  values lie within the range found for other continental basalts. There is a tendency for the initial  $\text{Sr}^{87}/\text{Sr}^{86}$  ratio to increase with increasing Rb/Sr; this may indicate that variable contamination of a parent basaltic magma by material of higher  $\text{Sr}^{87}/\text{Sr}^{86}$  and Rb/Sr has occurred

<sup>75</sup> Tatsumoto, M., Hedge, C. E., and Engel, A. E. J., 1965, Potassium, rubidium, strontium, thorium, uranium, and the ratio of strontium-87 to strontium-86 in oceanic tholeiitic basalt: *Science*, v. 150, p. 886-888.

prior to eruption. Apart from the question of genesis the geochemical data have important implications regarding stratigraphic correlations within the region of outcrop of the Columbia River Basalts.

#### **Lead isotopes and the age of mineralization—northwestern Montana and northern Idaho**

In parts of northwestern Montana and northern Idaho which are mainly underlain by rocks of the Belt Supergroup, in some localities it is difficult to determine the time of mineralization from field relationships. Preliminary isotopic analyses of lead from over 60 mines and prospects by R. E. Zartman indicate two distinct periods of ore genesis—one in the Precambrian synchronous with or soon after sedimentation of the Belt Supergroup, and the other in the Mesozoic-Cenozoic. The former gives rise to a lead of very uniform isotopic composition with model ages of 1.2–1.5 b.y., and the latter produces a lead which is more evolute and variable in isotopic composition. The use of lead isotopes to distinguish between Precambrian and Mesozoic-Cenozoic ore deposits allows one to recognize mineralization features which would not otherwise be obvious.

Major lead and silver deposits, including the important Coeur d'Alene mining district in Idaho and numerous smaller districts in Mineral County, Mont., are closely associated with the Osburn fault system and are here interpreted as being Precambrian in age. Mineralization apparently was controlled by this major fracture system, and is genetically unrelated to adjacent Cretaceous intrusions, such as the Gem stocks (although some minor deposits of probable Cretaceous age have been recognized within the North Gem stock). These results also provide additional evidence that a significant part of the structural development in this area occurred in Precambrian time.

A second major belt of Precambrian mineralization extends southward from near Bonners Ferry, Idaho, along the Idaho-Montana boundary, and joins the Osburn fault system in the vicinity of Thompson Pass. This belt includes the significant lead-zinc-copper occurrences of the Troy district, as well as other deposits along the general trend of the Cabinet Mountains and northern Bitterroot Range. A close spacial relationship exists in some places between this mineralization and a concentration of Precambrian sills of altered quartz diorite occupying part of the same area. Possibly these ore deposits and abundant basic igneous rocks define another Precambrian fracture system akin to, but less obvious than, the Osburn fault system.

A variety of deposits are found within the consider-

ably deformed Belt Supergroup rocks along the eastern flank of the Kootenai Arc mobile belt in Idaho. Included here are the once productive lead-silver mines of the Beauty Bay, Pend Oreille, and Boundary County districts. Some of the deposits are clearly related to silicic igneous rocks and accompanying faulting which mark the edge of the Kaniksu batholith, but others cannot easily be dated from field relationships. With few exceptions the ore deposits adjacent to the Kootenai Arc mobile belt appear to be Mesozoic-Cenozoic.

Several Mesozoic-Cenozoic lead-silver and gold-pyrite deposits occur in southern Lincoln and Sanders Counties, Mont. While these deposits lie in close proximity to the Snowshoe and Hope faults, it is not obvious from their structural settings that they should be of a different generation than Precambrian deposits also present in the area. The best clue to the young age of these particular occurrences comes from recent aeromagnetic surveys of northwestern Montana (J. E. Harrison, oral commun., 1970). Although the nearest outcrops of silicic igneous rocks are found 4 miles or farther away, a pattern of positive magnetic anomalies probably caused by shallowly buried stocks appears to correlate closely with these deposits. A similar anomaly surrounds the Gem stocks in Shoshone County, Idaho, where Cannon, Pierce, Antweiler, and Buck<sup>76</sup> found restricted occurrences of young mineralization within the Coeur d'Alene district.

Generally only small isolated deposits of both Precambrian and Mesozoic-Cenozoic age have been found in the weakly mineralized area northeast of the Cabinet Mountains. A notable exception is in the Hog Heaven district where rich, but limited, occurrences of lead-silver ore are associated with Tertiary volcanic andesites.

## **STABLE ISOTOPES**

### **Calibration of a sulfur isotope geothermometer**

A series of hydrothermal coprecipitation experiments were used by G. K. Czamanske and R. O. Rye to establish sulfur-isotope fractionation factors between sphalerite and galena. As indicated by theoretical calculations and analyses of coexisting mineral pairs, sphalerite preferentially concentrates  $S^{34}$ . Experimental values of the fractionation factor,  $\alpha_{S^{34}\text{-Gn}}$ , increase from 1.0009 at 600°C through 1.0023 at 275°C. Over the investigated temperature range the values of  $1,000 \ln \alpha_{S^{34}\text{-Gn}}$  are a linear function of  $1/T^2$ . The

<sup>76</sup> Cannon, R. S., Jr., Pierce, A. P., Antweiler, J. C., and Buck, K. L., 1962, lead-isotope studies in the northern Rockies, U.S.A., in Engel, A. E. J., James, H. L., and Leonard, B. F. (eds.), *Petrologic studies—a volume in honor of A. F. Buddington*: Geol. Soc. America, p. 115–131.

experimental technique involved simultaneous solution, transport, and coprecipitation of sphalerite and galena in 10-cm platinum tubes charged with 6*N* NH<sub>4</sub>Cl. Experiments were run under temperature gradients of about 5°C over the length of the tubes. The fractionation factors are considered to be equilibrium factors because they were approached from opposite sides of the equilibrium distribution. The applicability of the experimental curve to natural samples was tested on large crystals of sphalerite with included galena from several ore bodies. Filling temperatures of fluid inclusions in various generations of sphalerite range from 225° to 365°C. Maximum discrepancy between filling temperatures and temperatures indicated by  $\delta S^{34}$  values of apparently contemporaneous sphalerite and galena is about 40°C. Where sphalerite and galena precipitated at nearly the same temperature but clearly not contemporaneously, the isotope temperatures do not always agree well with the filling temperatures.

#### Antarctic tillite is nonmarine

Irving Friedman, D. L. Schmidt, and P. L. Williams determined O<sup>18</sup>-O<sup>16</sup> and C<sup>13</sup>-C<sup>12</sup> ratios of 26 samples of carbonate in Antarctic tillite and other rock. Previous workers have suggested that the tillites were laid down in the sea, but the isotope data definitely prove that the carbonates, at least, are of continental origin. Furthermore, the waters from which the carbonates precipitated are similar in isotopic composition to present-day coastal precipitation and quite different from Antarctic plateau precipitation.

#### Apatite-water oxygen-isotope relations

J. R. O'Neil (U.S. Geological Survey) and Antonio Longinelli (University of Pisa) calibrated the apatite-water oxygen isotope temperature scale. The hydroxyapatite-water fractionation curve is given by  $10^3 \ln \alpha = 1.62 (10^6 T^{-2}) - 7.04$ . The chlorapatite-water fractionation curve is given by  $10^3 \ln \alpha = 1.68 (10^6 T^{-2}) - 6.29$ . The ubiquity and ease of separation of apatites, in addition to its tendency to concentrate the light isotope of oxygen relative to silicates, make this isotope thermometer extremely useful.

Of chemical interest is the fact that the curves continue to go to increasingly more negative apatite-water fractionations with increasing temperature (−5.3 per mil at 700°C). It was expected to exhibit a minimum on a plot of  $\ln \alpha$  versus  $T^{-2}$ . Also of interest is the rather profound effect the —OH group has on the isotopic properties of apatites. Chlorapatites are approximately 1 per mil heavier than hydroxyapatites at equilibrium in the temperature range 250° to 700°C.

#### Nature of ore fluids at Calsapulca mine, central Peru

R. O. Rye (U.S. Geological Survey), in cooperation with F. J. Sawkins (University of Minnesota), studied the nature of the hydrothermal fluids responsible for the silver-lead-zinc-copper ores at the Calsapulca mine, central Peru. Studies of primary fluid inclusions indicate that the temperature of the hydrothermal fluids dropped from 370° to 260°C and that the salinity of the fluids varied erratically from 4 to 40 equivalent weight percent NaCl.  $\delta O^{18}$  values of quartz and early calcite indicate that the  $\delta O^{18}$  of the hydrothermal fluids was nearly constant ( $7.5 \pm 0.5$  per mil relative to SMOW<sup>77</sup>) and that the hydrothermal fluids were derived from a high-temperature silicate source.  $\delta O^{18}$  values of the late calcite, however, indicate that late hydrothermal fluids were distinctly different from the early fluids. The  $\delta C^{13}$  values of calcite indicate a deep-seated source for the early hydrothermal carbon but a limestone source for the later hydrothermal carbon. The narrow range of  $\delta S^{34}$  values for the sulfides indicate a deep-seated source for the hydrothermal sulfur. The  $\delta D$  values of inclusion fluids indicate that the ore was deposited from deep-seated waters distinctly different from the surface waters that deposited the late-stage gangue minerals.

### ADVANCES IN GEOCHRONOMETRY

#### Cambrian igneous activity in Colorado

A K-Ar age study by R. F. Marvin and R. L. Parker on alkalic rocks of the McClure Mountain Complex about 12 miles north of Westcliffe, Colo., indicated a Cambrian age for the intrusion. Determinations on biotite from syenite and nepheline syenite range from  $508 \pm 26$  to  $510 \pm 15$  m.y., and those on coexisting hornblende range from  $517 \pm 26$  to  $532 \pm 27$  m.y. The emplacement of the complex is interpreted to have occurred between 515 and 525 m.y. ago.

#### Uranium-series dating of Quaternary successions

From the results obtained by B. J. Szabo on uranium-series dating of fossil wood, fresh-water and marine shells, and bone samples from various continental and marine Quaternary deposits, the following conclusions can be drawn: (1) fossil wood is unsuitable for accurate dating because of unrestricted migration of uranium and daughter products in and out of the sample throughout time; (2) in general, fresh-water shells contain too much common thorium ( $Th^{232}$ ) with respect to uranium to be used for reliable dating; (3) most fossil marine shells do not remain an ideal closed system, but because only

<sup>77</sup> SMOW, standard mean ocean water.

uranium is found to be mobile the dating of these shells yields reliable dates by the "open system" dating method; and (4) dating of fossil bones appears to be very promising because several of the samples that have been dated indicate that uranium and daughter products remained in a closed system, thereby yielding concordant  $\text{Th}^{230}$  and  $\text{Pa}^{231}$  dates; this is the best evidence for reliability of this type of date.

### ISOTOPE HYDROLOGY

Isotope techniques are useful in solving several types of hydrologic problems. Radioisotopes artificially introduced into ground-water or surface-water systems can provide information on direction, rate, and volume of water flow. Postulated effects of radioisotopes on ground water are given in the section, "Investigations Related to Nuclear Energy," p. A177-A184.

Environmental isotopes provide information about ground-water flow rates and mixing phenomena and about chemical interactions within an aquifer. Geochemical studies using carbon isotopes have been carried out by B. B. Hanshaw, William Back, and Meyer Rubin, and by F. J. Pearson, Jr., and Irving Friedman. The studies are described in the section, "Geochemistry of Water," up. A130-A134.

To use environmental isotopes, their concentrations in the input to the system being investigated must be known. The results of several studies of the radioisotope content of various natural waters are reported here.

#### Radium and uranium in surface water

Sampling and analysis of 57 streams at points designated as hydrologic benchmark stations and of 26 major rivers in a radiochemical network system have been completed during the last 3 years. V. J. Janzer reported that the highest concentration of dissolved uranium found in the benchmark samples was  $6.5 \mu\text{g/l}$  in a North Dakota stream. Samples obtained from other midwest and western states including Montana, Iowa, Nevada, Utah, Texas, and South Dakota exhibited uranium concentrations of 4.6, 3.6, 2.2, 1.1, 1.1, and  $1.0 \mu\text{g/l}$ , respectively. Radium concentrations in benchmark streams are generally less than  $0.1 \text{ pCi/l}$ , although one sample from North Carolina was found to contain  $2.4 \text{ pCi/l}$  of radium-226.

Five-year average concentrations of the Colorado and Missouri Rivers were 6.8 and  $4.8 \mu\text{g/l}$  uranium, respectively, the highest concentrations of natural radioactivity observed to date in the major river network system. Radium levels were approximately 0.2 and  $0.1 \text{ pCi/l}$ , respectively, during the same period.

Uranium levels as high as  $3.4 \mu\text{g/l}$  have been observed in the Snake River in Washington. Radium concentrations in this river during the period of study did not exceed  $0.05 \text{ pCi/l}$ .

V. J. Janzer also reported relatively high levels of natural radioactivity occurring in several South Platte River tributaries in Colorado. These streams, the St. Vrain, Big Thompson, and Cache Le Poudre, contained 26, 40, and  $34 \mu\text{g/l}$  of dissolved uranium, respectively. Dissolved radium levels of 0.08, 0.16 and  $0.25 \text{ pCi/l}$  respectively, were found in the same samples. The uranium and radium contributed by these streams is largely responsible for the relatively high levels of natural radioactivity which have been observed in the South Platte. Uranium concentrations gradually increase downstream exceeding  $60 \mu\text{g/l}$  at Balzac, Colo. Radium concentrations did not exceed  $0.1 \text{ pCi/l}$  in the same reach.

The observed increase in uranium concentration is believed to result primarily from the combined effects of high initial concentrations contributed by major tributaries and drainage from sedimentary deposits high in natural radioactivity.

#### Tritium in precipitation and surface water

Tritium concentration and rainout for United States precipitation during 1966, 1967, and 1968 were reported by G. L. Stewart (University of Massachusetts) and T. A. Wyerman (r1774). They found that the arithmetic mean weighted average tritium concentration for 12 network stations decreased about 38 percent in 1966 compared to 1965, about 35 percent in 1967 compared to 1966, and about 30 percent in 1968 compared to 1967. The 1966, 1967, and 1968 values were only 20, 13, and 9 percent, respectively, as great as they were in 1963. Tritium data for special samples collected after the Chinese nuclear bomb tests on May 9, 1966, and June 17, 1967, indicated that no measurable tritium was added to United States precipitation as a result of these nuclear explosions.

The results of tritium analyses of samples from 20 streams in the conterminous United States and Alaska from 1961 through 1968 were reported by Wyerman, R. K. Farnsworth, and Stewart.<sup>78</sup> Although detailed interpretation of the data has not been completed, certain trends are obvious from the raw data. The large pulse of precipitation tritium due to thermonuclear testing is reflected in all the streams. Also apparent are the seasonal, latitudinal, and continental effects noted in precipitation. The amount of ground-

<sup>78</sup> Wyerman, T. A., Farnsworth, R. K., and Stewart, G. L., 1970, Tritium in streams in the United States, 1961-68: U.S. Dept. Health, Education, and Welfare, Radiological Health Data and Repts., v. 2, no. 9, p. 1-50. [In press]

water flow relative to runoff appears to affect tritium content of streams as might be expected since ground-water response to tritium in precipitation is obviously much slower than stream response. During the early part of the period of record, most streams contained considerably less tritium than did precipitation, whereas later the concentration of tritium in streams often exceeded that of precipitation.

The Colorado River at Cisco, Utah, and most of the other sampled rivers reached their maximum tritium levels in 1963-64, whereas the Colorado River near Yuma, Ariz., did not reach its highest level until 1966-67. The Yukon River in Alaska carried the highest concentration derived from precipitation, whereas the Kissimmee River in Florida had the lowest. Although their basins adjoin, the Potomac River had tritium levels significantly lower than the Ohio River. Tritium concentrations of the Klamath River in California and Oregon were lower than those of the Sacramento River in California.

## SEDIMENTOLOGY

Sedimentology, the study of sediments and sedimentary rock, encompasses investigations of principles and processes of sedimentation and includes development of new techniques and methods of study. Sedimentology studies in the U.S. Geological Survey are directed toward two ends: (1) solution of water-resources problems, and (2) determination of the genesis of sediments and application of this knowledge to sedimentary rocks for more precise interpretation of their depositional environment. Many studies in the Geological Survey involving sedimentology are directly applied to other topics such as marine, economic, and engineering geology, and to regional stratigraphic and structural studies; these are presented 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. Knowledge of erosion processes, the movement of sediment in rivers and streams, and the deposition of sediment in stream channels and reservoirs is of great economic importance to the Nation.

## TRANSPORTATION

### Comparison of sediment transport and resistance to flow in a flume with that in a field channel

C. H. Scott, R. S. McQuivey, and V. R. Schneider reported that bed material from the Rio Grande conveyance channel near Bernardo, N. Mex., has been used in an 8-foot-wide flume at Colorado State Uni-

versity to compare flow and sediment transport characteristics of a large recirculating flume with those of a field stream.

In both the field and laboratory systems, (1) the measured turbulence scale increases with an increase in the depth of flow, (2) the turbulence intensity varies from 2 to 10 times the fall velocity of the suspended sediment particles, (3) the suspended-sediment concentration increases with an increase in the turbulence intensity, and (4) for a particular turbulence intensity, the suspended-sediment concentration decreases as the scale of flow increases.

The sand waves found on the beds of both the flume and field channels were characterized statistically. Bed forms for both field and laboratory appear identical and had the same relative height-to-length ratio. However, bed forms having identical height-to-length ratio occurred at different velocities and slopes for the two systems.

Resistance to flow, as measured by the resistance coefficient,  $C/\sqrt{g}$ , (where  $C$  is Chézy's coefficient and  $g$  the acceleration of gravity) can be described by the hydraulic variables, depth or mean velocity, and bed-form statistics. For comparable values of relative height-to-length ratio and the mean bed-material size, values of  $C/\sqrt{g}$  are approximately the same in both flume and channel.

Sediment transport per foot of width of channel as a function of mean velocity indicated a separation between the relation for dunes and flat bed.

## VARIABILITY OF SEDIMENT LOAD IN DRAINAGE AREAS

### Sediment data for streams in California

B. L. Jones and N. L. Hawley used sediment data collected from the western tributaries of the Sacramento River to compute annual sediment yields. Average annual sediment yield ranged from less than 100 to more than 3,000 tons per sq mi, representing deposited volumes of 0.09 to 2.03 acre-ft per sq mi. Computed bedload discharge ranged from 2 to 39 percent of suspended-sediment discharge. The highest sediment yields were from basins in the Coast Ranges, and the lowest are from streams draining the Great Valley.

J. M. Knott reported that long-term sediment yields at sediment stations in the Middle Fork Eel River basin are being estimated from sediment-transport curves and flow-duration data. An extraordinary flood (December 1964) drastically changed the then-existing water-sediment discharge relations; about five times as much sediment was transported at a

given flow after the flood than was transported before the flood. Within 2 years after the flood the sediment-transport rates began to decrease and 5 years after were approaching pre-flood levels. These high yields, in general, persisted longer in the larger drainage areas than in the smaller ones. Sediment yields were determined by weighing the high-yield postflood years according to their frequency of 100 years rather than as average years.

#### **Sediment control in highway construction**

Five small streams in adjacent drainage basins are currently being monitored by L. A. Reed and J. F. Truhlar, Jr., to determine the effects of highway construction on sediment discharge. Erosion control measures used in highway construction will be evaluated in four of the drainage basins with the fifth basin being used as a control. Prior to construction, annual sediment discharge from the basins averaged about 110 tons per sq mi, with base-flow conditions yielding turbidities and sediment concentrations less than 3 Jackson Turbidity Units (JTU) and 1 mg/l, respectively. Maximum turbidities and sediment concentrations of 600 JTU and 2,800 mg/l, respectively, occurred during and directly after rainfall intensities greater than 2 in. per hr in Cumberland County, Pa.

### **VARIABILITY OF SEDIMENT YIELD IN STREAMS**

#### **A mudflow in Lake Tahoe basin, Nevada**

A report by P. A. Glancy disclosed that a mudflow in the Second Creek drainage on August 25, 1967, deposited more than 50,000 cu yd of debris along the lower part of the drainage near the shore of Lake Tahoe. The mudflow was caused by intense thunder-showers in the high-altitude parts of the drainage, resulting in appreciable sheet and rill erosion of the nonforested uplands. The sheet- and rill-erosion products were rapidly flushed downstream and were supplemented by debris derived by channel scouring. The resultant water-sediment mixture evolved into a mudflow, and much of the debris subsequently was deposited along the flatter parts of the drainage in the area inhabited by people. Landscape denudation in the drainage caused by the event was estimated to average about 0.02 foot.

#### **Studies of large rivers**

D. E. Everett reported that suspended-sediment concentrations in the Mississippi River at Red River Landing (near Tarbot Landing), La., ranged from 13 to 2,400 mg/l for the period 1949-64. Concentrations were less than 1,000 mg/l for 92 percent of the

time and less than 450 mg/l for 50 percent of the time. The average annual suspended-sediment load was 750,000 tons per day, ranging from 288,000 tons per day in 1963 to 1,580,000 tons per day in 1951. In 1950, the highest flow year during this period, approximately 45 percent of the total load of 548 million tons (1.5 million tons per day) was discharged during the high flow months of January, February, and March. This amounted to 2.7 million tons per day for this 3-month period.

### **DEPOSITION**

#### **Sediment structure**

E. D. McKee made studies of sand dune development involving the manner of growth, characteristics of resulting structures, and rates of movement. The study was made partly in the field using markers to record changes during growth, and partly in the laboratory where processes were tested and resulting forms compared with corresponding natural features.

Measurements of dune movement were recorded for (1) short-term intervals, introducing magnetite marker laminae at half-hour periods; and (2) long-term intervals, by measuring from fixed stakes and by calculating from air photographs taken at 6-month periods.

Sediment-structure data determined by these studies help in the recognition of depositional environments, and are especially significant in the location and characterization of reservoir rocks for petroleum and other fluids. The data also are valuable in studies on the migration of liquids where sediment structures may be modifying, if not controlling, factors.

#### **Iceberg-rafted sediment in Glacier Bay, Alaska, and in the Precambrian Gowganda Formation, Canada**

Observations of icebergs in a modern glacial marine environment indicate that ancient rocks that received iceberg-rafted material should contain: (1) local concentrations of stones that originated when icebergs overturned, and (2) small pellets of till that were originally sediment, filling the spaces between clear ice crystals.

The till pellets are especially significant in identifying an ancient glacial setting because they originate through a process unique to glaciers—the flow- and recrystallization-induced segregation of originally disseminated fine sediment. Thus the pellets, freed by melting and deposited by iceberg-rafting, would reliably indicate the presence of glacial ice in an environment of deposition. A. T. Ovenshine (r1290) reported that in the Gowganda Formation, Canada, a Precambrian glacial deposit, strata that contain outsized, pre-



sumably iceberg-rafter stones also contain abundant small flattened clasts of unsorted graywacke interpreted as the lithified counterparts of the till pellets observed on modern icebergs.

## GLACIOLOGY

Measurement of water, ice, and heat balances at a number of selected glacier basins is one of the major contributions of the United States to the International Hydrological Decade program. These efforts are primarily directed toward gaining a better understanding of the relation of glaciers and glacier runoff to the meteorologic environment. In addition, much valuable information is obtained on high-mountain hydrology. Although few basic data are available, this subject is important to water-resources investigations because of the high precipitation rates and enormous volumes of water temporarily stored during the winter months.

Glaciers may change markedly in response to minor changes in climate or may fluctuate in response to other changes in their environment. Measurement and understanding of these glacier fluctuations may lend valuable insight into the nature of the climatic variations or signal important changes in temperature or other properties of the bedrock.

### Hydrologic effects of glaciers

Attempts to relate glacier runoff and precipitation to ice storage changes measured on a glacier by classical stratigraphic methods may lead to error because summer ablation surfaces form at different times in different places. A new definition of mass-balance concepts by L. R. Mayo, M. F. Meier, and W. V. Tangborn relates stratigraphic system values and field measurements to the mass inputs and outputs of a hydrologic year. An annual-balance system is used, together with separate material balances, so that values of ice melt, snow accumulation, and so forth, can be measured.

Ice and water balance studies by Mayo on two glacial basins in Alaska contributed to the knowledge of mountain precipitation patterns. A network of gages and detailed mapping of snow accumulation in these basins showed that annual precipitation increases markedly with altitude in the Alaska Range and ranges from 0.25 m in the lowlands to 2.0 m at 2,000 m altitude. In the Kenai Mountains of the Maritime zone in south-central Alaska, the minimum annual precipitation, 1.2 m, occurs at 1,000 m altitude. Perpetual cloudiness at low altitudes increases the precipitation, and at 2,000 m altitude precipitation

reaches a maximum of 4.0 m. This precipitation distribution had not been documented before, and the precipitation amounts are far greater than usually reported.

The significant contribution of glacier runoff to summer streamflow in the North Cascades, Wash., especially during periods of low precipitation, was revealed by calculations by Tangborn. For instance, in August and September 1966 (a warm, dry summer), glacier snow and ice melt contributed 66 percent to the Thunder Creek runoff and 47 percent to the Stehekin River, although glaciers cover only 14 percent of the Thunder Creek drainage basin and only 3 percent of the Stehekin River basin. During 1964 (a cool, wet summer), the glaciers contributed 14 and 21 percent, respectively, of the August-September streamflow.

Another important characteristic of the hydrology in the North Cascades is the disproportionately large contribution of high-altitude runoff to lowland streams. A study of the streamflow records of Salix Creek and the Cascade River by Tangborn showed the effect of the alpine snowpack on low-altitude runoff during winter storms. For example, during the peak of one winter storm in December 1966, the areas above 1,600 m altitude, in the Cascade Basin making up less than 25 percent of the area, produced over 40 percent of the flow. Thus, high-altitude areas, even though small in extent, can be important sources of water during the winter season.

### Flow of water through glaciers

W. J. Campbell and L. A. Rasmussen used numerical modeling techniques to study the flow through a glacier of the melt water produced at its surface by the absorption of solar radiation and turbulent heat transfer. Parabolic partial differential equations were derived by assuming the glacier to act as if it were a porous medium in which Darcy flow exists. This is a simplification of the porous-medium theory used in ground-water studies owing to the assumption of a single glacier permeability both for the saturated and unsaturated zones. The absorbed solar radiation was computed by approximating the glacier surface by polyhedral faces with known albedo distribution; then, at any time, the received energy was determined by calculating the component of sunlight on each face. The model was applied to the South Cascade Glacier, Washington, for a clear 6-day period in 1961 of nearly constant conditions day to day; the computed outflow compared well with the measured outflow for this period.

### Glacier dynamics

Three-dimensional, time-dependent glacier flow can be described by parabolic differential equations derived by vertically integrating the Navier-Stokes equation and assuming both a Newtonian viscous-flow law and a linear relation between volume transport and bottom shear stress. The solution of the equations in finite-difference form was accomplished on a high-speed digital computer by W. J. Campbell and L. A. Rasmussen for hypothetical valley and cirque glaciers, for a variety of annual mass-balance curves. A temporary reduction of the bed friction, to 5 percent of its original value for 1 year, yields a glacier surge and recovery resembling typical observed surges.

### Glaciers on volcanoes—recent changes

Slight changes in heat flow or the movement of heated ground water in a volcano may produce large changes in its ice and snow mantle. A. S. Post observed that a cascading glacier on Mount Redoubt, Alaska, was almost completely eliminated by the eruption of 1963, but on the glaciers of Mount Spur, Alaska, only debris-flow deposits and an ash bed in the accumulation zone marked the eruption of 1953. Recent debris flows on glaciers occurred on Mounts Illiamna, Alaska, and Garibaldi, Canada. Since 1955, five mudflows with associated rock and ice avalanches have swept down Boulder Glacier, Mount Baker, Wash. After the remarkable 1967 jökulhlaup from South Tahoma Glacier, Mount Rainier, Wash., the tongue of this previously advancing glacier has stagnated. An unusually broken, fast-moving zone on Emmons Glacier, also on Mount Rainier, developed in 1969.

### Icebergs for water supply

W. F. Weeks (U.S. Army Cold Regions Research and Engineering Laboratory) and W. J. Campbell analyzed the feasibility of towing large icebergs to arid regions as a source of fresh water. Only in Antarctica are adequate supplies of large tabular icebergs available. Calculations of the melting in transit indicated that significant amounts of ice will remain if large icebergs are slowly towed in a manner to take advantage of winds and ocean currents. Currently available tugs are capable of towing large bergs at the correct velocities, and it appears that the idea may be economically feasible.

## PALEONTOLOGY

Research by paleontologists of the U.S. Geological Survey involves biostratigraphic, taxonomic, and phy-

logenetic 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 and to application of the mapping to synthesis of the geologic history of North America and the surrounding oceans. Significant results of paleontologic research attained during the past year, many of them as yet unpublished, are summarized in this section by major geologic age and area.

Many paleontologic determinations are carried out by paleontologists of the Geological Survey in cooperation with Survey colleagues. The results of these investigations are reported elsewhere in this chapter and are generally listed in the index as the entries "paleontology" or "stratigraphy" under names of States.

## PALEOZOIC OF THE EASTERN STATES

### Ordovician stratotypes in Ohio, Indiana, and Kentucky

John Pojeta, Jr., R. J. Ross, Jr., O. L. Karklins, and W. T. Dean (Geological Survey of Canada) collected stratotype sections for the Upper Ordovician Eden, Maysville, and Richmond Stages in May 1969. These collections are now being processed by the above workers and J. W. Huddle, J. M. Berdan, E. L. Yochelson, W. A. Oliver, Jr., and R. B. Neuman. They will provide the first documentation of the actual vertical ranges of species which for decades have been used in a casual way for eastern North American Late Ordovician correlations. By comparison of the stratotypes to other measured sections in the tristate area of Ohio, Indiana, and Kentucky a biostratigraphic zonation of the Ordovician rocks in this area based on the entire fauna is emerging.

Eighteen tons of Ordovician limestone containing silicified fossils from the tristate area of Ohio, Indiana, and Kentucky were processed by acid etching. All megafossils have not yet been counted, but it is estimated that close to 200,000 specimens were obtained. The groups most abundantly represented are brachiopods, pelecypods, bryozoans, gastropods, cephalopods, and anthozoans. Innumerable microfossils have been obtained; these are largely conodonts, scolecodonts, and ostracodes.

### Ordovician bryozoan assemblage zones

O. L. Karklins recognized two bryozoan assemblage zones in the Lexington Limestone of central Kentucky. The lower zone contains species of *Batostoma*, *Constellaria*, *Eridotrypa*, *Hallopora*, *Hemiphragma*, *Heterotrypa*, and *Homotrypa*. The upper zone is characterized by different species of *Constellaria*, *Eridotrypa*, *Hallopora*, and *Heterotrypa*. In the reference section of the Lexington Limestone, central Kentucky, the boundary

between the lower zone and the upper zone is placed near the top of the Brannon Member of the Lexington Limestone. This boundary between the two assemblage zones is of stratigraphic interest because the lower zone contains bryozoans that are typically Middle Ordovician in appearance, whereas those in the upper zone are similar to bryozoans from the Upper Ordovician as it has been understood in the tristate area of Ohio, Indiana, and Kentucky. At present both zones can be recognized in several outcrop areas of the Lexington Limestone and are useful for correlation.

#### Life habits and distribution of the brachiopod *Pentagonia*

*Pentagonia*, a specialized meristellid brachiopod with a restricted stratigraphic and geographic distribution in the Devonian of eastern North America, was studied by J. T. Dutro, Jr. The genus is characterized by its external pentagonal shape, both in plan view and in posterior outline. *Pentagonia* arose from *Meristella lentiformis* in Oriskany time and was widely distributed in eastern North America during Schoharie and Onondaga time. The youngest species flourished in Centerfield time and was particularly abundant in the Beechwood Limestone Member of the Sellersburg Limestone of southern Indiana and Kentucky. The genus became extinct before the end of the Middle Devonian. *Pentagonia* had no functional pedicle, and shell shape was apparently related to a free-living condition on the sea floor.

#### Pennsylvanian palynology of Kentucky

Thirty-four genera were identified by R. M. Kosanke from the Lee, Breathitt, and Conemaugh Formations of eastern Kentucky. Quantitatively, *Lycospora* and *Densosporites* are important in the Lee Formation, whereas *Lycospora*, *Laevigatosporites*, and *Densosporites* are important in the Breathitt Formation. *Schulzospora rara* characteristically occurs in coals from the Lee Formation and in two coals at the base of the Breathitt Formation. *Schopfites dimorphus* and *Laevigatosporites pseudothiessenii* have important range zones near the top of the Breathitt Formation.

This palynological information is utilized in correlation of economically important coals of eastern Kentucky. The results are an aid to geologists mapping and estimating coal reserves in connection with the cooperative project of the Kentucky Geological Survey and the U.S. Geological Survey.

### PALEOZOIC OF THE WESTERN STATES

#### Corals and brachiopods from the Amsden Formation

A study of the Amsden Formation of Wyoming by W. J. Sando, Mackenzie Gordon, Jr., and J. T. Dutro,

Jr., including detailed investigation of its brachiopod faunas by Gordon and corals by Sando, showed that deposition of the Amsden took place during parts of two geologic periods. The fossils range from Late Mississippian (Chester) to Middle Pennsylvanian (Atoka) in age.

Distribution of the fossil faunas in four members of the formation indicates a general eastward transgression of the sediments, supporting the findings of other geologists who reached the same conclusions largely on lithologic grounds. The unfossiliferous Darwin Sandstone Member at the base of the formation has an age within the span of middle Meramec to early middle Chester in western Wyoming and probably late Chester in the north-central part of the State. An unnamed limestone member above the Darwin in western Wyoming is middle to early late Chester in age. The Horseshoe Shale Member is late Chester in age in western Wyoming and Morrow (Pennsylvanian) age in the Rawlins uplift in Carbon County. Finally, the Ranchester Limestone Member, the uppermost in the formation, is Morrow in age over much of western and central Wyoming but reaches Atoka age in the Rawlins uplift.

The study includes a reexamination of all fossils previously described and most fossils previously listed from the Amsden.

#### Devonian rugose corals of the Great Basin

Studies by C. W. Merriam indicated that the rugose corals of Great Basin, Devonian, shelf seaways underwent 3 major bursts of evolutionary activity: (1) early Middle Devonian (early Eifelian), (2) medial Middle Devonian (late Eifelian), and (3) Late Devonian (Frasnian). No Rugosa are known in the highest Devonian (Famennian) of this province. The first major evolutionary burst, that of Devonian coral zone D, is followed by even greater differentiation of coral families in coral zone F marked by spread of Disphyllidae and Digonophyllidae, with disappearance of Hallidae and Bethanyphyllidae of older Devonian coral zones. Late Devonian coral zone I has few surviving rugose coral families, but the newly arrived Phillipsastraeidae evolved rapidly and filled many of the ecologic gaps.

Of Early Devonian Halliidae, the endemic *Papillophyllum* and a related genus are known only in the Great Basin province. Coral zone D Digonophyllidae such as *Mesophyllum* and *Zonophyllum* provide significant ties with the Rhine Valley Middle Devonian of Germany.

#### Devonian graptolites of southeastern Alaska

The finding of two new species of *Monograptus* (*M. pacificus* and *M. craigensis*) in Devonian black shale

and slate on Noyes Island and along the west shore of Prince of Wales Island, southeastern Alaska, raised to seven the number of monograptid species known from the upper Lower Devonian (Pragian) and possibly lower Middle Devonian. The occurrence of *M. aequabilis notoaequabilis* in association with *M. pacificus* is believed by G. D. Eberlein and Michael Churkin, Jr., to represent the highest graptolite horizon known and extends the known geographic distribution of the former to North America for the first time (in addition to Australia, southeast Asia, and Europe). This suggests that the last survivors of *Monograptus* had a cosmopolitan distribution and a rather uniform assemblage of species.

#### Great Basin trilobites

Preliminary analysis of faunal and stratigraphic data from the Notch Peak, Whipple Cave, Windfall, and Hales Formations in the central Great Basin, Nevada and Utah, by M. E. Taylor suggested that at least seven faunal zones, ranging in age from Late Cambrian (late Franconian-Trempealeauan) through earliest Ordovician, can be locally recognized.

Trilobites from the Notch Peak Limestone (studied with the cooperation of L. F. Hintze, Brigham Young University) demonstrated that a faunule composed of *Highgateella*, *Hystericurus*, *Missisquoia*, and *Symphysurina*, occurs in the uppermost part of the Notch Peak Limestone. The faunule is characteristic of the lowest Ordovician *Missisquoia* Zone as recognized in Vermont, central Texas, and Oklahoma. The stratigraphic occurrence of the *Missisquoia* Zone below the *Symphysurina* Zone B in the House Limestone provides refinement in the Ross-Hintze, Lower Ordovician zonal scheme, and a more precise basis for recognition of the Cambrian-Ordovician boundary in the Western United States.

#### Oldest Silurian graptolites in the Great Basin

Graptolites collected by F. G. Poole and T. E. Mullen, from the upper part of the basal cherty unit of the Roberts Mountains Formation in the Toquima and Monitor Ranges of central Nevada, were identified by W. B. N. Berry (University of California, Berkeley) as representing zones 18 and 19 of the British graptolite zonation.<sup>79</sup> These Early Silurian (pre-late Llandovery) graptolites are the oldest collected from the formation and represent the oldest Silurian graptolites reported from the Basin and Range region.

#### North American reference section for lower Famennian

Conodont zonation of the West Range Limestone and lower part of the Pilot Shale at Bactrian Mountain

in the Pahrnagat Range of southeastern Nevada is being investigated by C. A. Sandberg. These strata contain an unusually thick and unbroken sequence of Late Devonian (early Famennian) conodont faunas ranging from the middle *Palmatolepis crepida* to the lower *Palmatolepis quadrantinodosa* Zones. Included within this sequence are several apparently new faunas and many transitional species that reveal the phylogeny of currently known species of conodonts. This sequence provides a conodont reference section for part of the lower Famennian in North America.

#### Ordovician graptolite zonation in transitional facies of south-central Nevada

Graptolites collected by F. G. Poole and R. J. Ross, Jr., from the upper Zanzibar Limestone and overlying Toquima Formation at Wall Canyon in the southern Toiyabe Range, were identified by Ross as representing zones 5 through 15 of the British graptolite zonation.<sup>79</sup> These late Arenig through Ashgill graptolites indicate an unbroken succession of upper Lower through Upper Ordovician strata in this area. Early Ordovician graptolites of zones 1 through 4 have not yet been found here, but these forms are sparse in the Basin and Range region. The metamorphosed and highly deformed lower Zanzibar Limestone, which has yielded no fossils, may represent zones 1 to 4. If so, a complete succession of Ordovician strata occurs at Wall Canyon. A similar faunal and lithologic sequence is also recognized to the east in the Manhattan mining district where only fragmentary sections are found.

#### Glass Mountains Permian brachiopods related to bioherms and reefs

Mound-shaped organic buildups with self-supporting frameworks of algae, bryozoans, and to lesser extent, corals and brachiopods, are numerous in the Glass Mountains Permian. Studies by R. E. Grant showed that the earliest is a bioherm in the Gaptank Formation, and that the number of bioherms increases sporadically upward in the section, reaching a climax of size (up to 80 feet high) as well as number in the Road Canyon Formation, then ceasing abruptly, with no bioherms in the Word Formation. Late Permian reef development took place in the Guadalupe Mountains, in form of the Capitan and associated reefs, and their stratigraphic equivalents. Brachiopods can be grouped into three categories: those adapted for reef dwelling, those better suited to life on open substrate, and ubiquitous forms. The proportion of ubiquitous forms (attached by pedicle) in the fauna increased steadily through the section; the Capitan reef complex contains nearly 80 percent of them, and the Capitan Limestone itself, supposedly the greatest of all

<sup>79</sup> Elles, G. L., and Wood, E. M. R., 1901-18, A monograph of British graptolites: Paleontographical Soc. London, 539 p.

Permian reefs, contains only about 6 percent reef-dwelling brachiopods. Perhaps significantly, the Mesozoic is dominated by pediculate brachiopods rather than the widely varying, spiny, and unattached forms that give the Permian its distinctive aspect. The biohermal environment supported a greater diversity of species than either the open substrate or the "reefy" environment of the Capitan and its associates.

## MESOZOIC OF THE UNITED STATES

### Jurassic Foraminifera from Alaska

A small foraminiferal fauna of lowermost Bajocian Age found by H. R. Bergquist in outcrop samples associated with diagnostic megafossils is the first known occurrence of Middle Jurassic Foraminifera from Alaska. Additional species came from a core originally reported as barren in Topagoruk test well 1 in northern Alaska. Middle Jurassic Foraminifera are sparingly known from Saskatchewan, but they have not been adequately described. Late Middle Jurassic (Bathonian) foraminifers are known from the Ellis Group at the type locality in Montana. The northern Alaska Bajocian fauna significantly extends the Jurassic faunal sequence from the earlier Pliensbachian and Toarcian faunas described by Tappen in 1955.

### A Campanian *Inoceramus* from the Yakutat Group in Alaska

A well-preserved specimen of *Inoceramus schmidtii* Michael collected from the vicinity of Russell Fiord indicated a Campanian Age for at least part of the Yakutat Group. The fossil, which was collected by George Plafker and identified by D. L. Jones, is the first specifically identifiable megafossil found to date in the thick sequence of flysch deposits that make up the Yakutat Group.

### Key western interior ammonites found in the Upper Cretaceous of Delaware

W. A. Cobban (p. D71-D76) reported that two species of Late Cretaceous ammonites, *Didymoceras stevensoni* (Whitfield) and *Exiteloceras jenneyi* (Whitfield), previously known only from the western interior of the United States, were discovered recently on the south side of the Chesapeake and Delaware Canal in New Castle County, Del. The specimens, found by members of the Monmouth Amateur Paleontologists Society (West Long Branch, N.J.), were made available to the U.S. Geological Survey for study by Mr. Harold Mendryk, North Arlington, N.J. Although the fossils were found as float, matrix attached to them suggests that *D. stevensoni* came from the glauconitic Marshalltown Formation, whereas

*E. jenneyi* probably came from the overlying Mount Laurel Sand. The find is important because it offers the possibility of direct correlation of western interior strata with Atlantic coast deposits.

### Late Cretaceous Foraminifera from New Mexico

The common occurrence of the planktonic species *Marginotruncana renzi* (Gandolfi) and *M. marginata* (Reuss) in a few samples give some evidence that the shale beds immediately below the Fort Hayes Limestone Member of the Niobrara Formation are Coniacian in age. In general, however, H. R. Bergquist found that the planktonic forms occurring in the San Juan samples are relatively long ranging, Late Cretaceous species and contribute little to a closely defined age determination. The relative proximity of the faunal assemblages of the basal Niobrara above the Juana Lopez Member of the Mancos Shale in the eastern part of the San Juan Basin suggests a thinning of the beds of the Carlile Shale Member of the Mancos Shale immediately overlying the Juana Lopez Member. This interval appears to thin northward from a maximum thickness of 200 to 250 feet to a feathered edge, and suggests a time hiatus somewhere within it.

### Nonmarine Early Cretaceous ostracodes of Nevada

I. G. Sohn (p.0435) described *Cypridea* (*Cypridea*) *pecki* n. sp. and *C. (Bisulcocypridea) bicostata* n. subg., n. sp. from a nonmarine sequence in Elko County, Nev., that is tentatively correlated with the Newark Canyon Formation in the Eureka District. *C. (C.) pecki* was previously recorded from the Draney Limestone (upper Aptian) of Idaho and Wyoming as *Cypridea diminuta* Vanderpool, 1928, described from rocks of early Albian Age in the Gulf coast. Based on the new species, the rocks in Elko County and possibly their equivalents in the Eureka district are late Aptian in age. The new subgenus *Bisulcocypridea* contains eight previously described species and subspecies from Africa, Asia and North America, having a stratigraphic range of Lower Cretaceous to Eocene. The presence of this subgenus, therefore, allows differentiation between Jurassic nonmarine sediments and Cretaceous to Eocene sediments.

### Late Cretaceous Foraminifera from Georgia and Alabama

In studies of the Foraminifera assemblages in Upper Cretaceous rocks of the Chattahoochee River region of Georgia and Alabama, H. R. Bergquist found that the faunas appear to be subtropical but lack certain tethyan planktonic Foraminifera such as *Abathomphalus* and *Bifarina*. *Pseudoguembalina costulata*

of late Campanian-Maestrichtian Age appears only in the Ripley Formation. *Guembelitra cretacea*, an early Maestrichtian index form is found exclusively in the Ripley and Providence Sand except for one occurrence of numerous specimens near the base of the Blufftown Formation at Snake Shoals, Ala. *Planoglobulina glabrata* of Campanian Age is restricted to the Blufftown. Among benthonic types, *Bolivina incrasata* and *Loxostomum eleyi* of late Campanian Age are restricted to the Blufftown and Cusseta Sand. *Kyphopyxa christneri* of Austin and Taylor age is confined to the Blufftown, and *Pulsiphonina prima* of Navarro age is found only in the Ripley. Nodosarids appear to decrease slightly from an average of about 40 percent of the fauna in the Blufftown to about 27 percent in the Ripley and about 5 percent in the Providence. Agglutinate forms are a minor part of the faunas of all formations.

## CENOZOIC OF THE UNITED STATES

### Atlantic coast Miocene depositional patterns

The examination of paleontologic and sedimentologic data by T. G. Gibson from onshore outcrops and well sections and offshore dredge hauls showed that although the Atlantic margin received little sedimentation during the Late Cretaceous and early Tertiary, a considerable increase in detrital material is found in the Miocene. The return to a detrital influx is found earlier in New Jersey than in Virginia and North Carolina to the south. This suggests a rejuvenation of the Appalachian source area during the middle and late Miocene, with a probable north to south progression. As a result the Miocene strata in New Jersey are organic rich silts and sands, while equivalent strata in North Carolina are phosphorites and limestone.

### New toothed whale from the Yorktown Formation in Virginia

A small whale skull collected by Brian Burdette and Charles Carter, junior high school students from Hampton, Va., from the uppermost Yorktown Formation in a well-known collecting locality known as Rice's Pit in Hampton, Va., was identified by F. C. Whitmore, Jr., as belonging to the family Delphinapteridae, toothed whales represented by the modern beluga (small Arctic white whale) and narwhal. The fossil skull, besides displaying characters seen in modern Delphinapteridae, has some palatal details resembling the modern pilot whale *Clobicephala*. The structure of its rostrum is more primitive than in any of the above-mentioned genera, but the skull is more advanced in structure than those of toothed whales found in the Chesapeake Group, which precedes the Yorktown in

Maryland and Virginia. Representatives of the Delphinapteridae have not previously been reported in beds older than Pleistocene. Coupled with the discovery in 1960, also in Rice's Pit, of a balaenid whale of modern aspect,<sup>80</sup> this skull is added evidence that the Yorktown cetacean fauna is considerably advanced over those of earlier Miocene formations in the middle Atlantic area.

### Giant pig from Alabama

R. H. Kilpatrick, of Milton, Fla., presented to the Smithsonian Institution three teeth identified by F. C. Whitmore, Jr., as belonging to *Dinohyus hollandi* Peterson, the largest pig known. The teeth were found on the bottom of the Conecuh River, Escambia County, Ala., at approximately the contact between the Byram Formation (Oligocene) and the Catahoula Sandstone and Paynes Hammock Sand (Miocene). *Dinohyus* is a short-lived genus, being known only from the early Miocene and representing the end of the line of the family Entelodontidae. It was first found in western Nebraska, and has also been reported from South Dakota, Wyoming, South Carolina, New Jersey, and from the Oakville and Fleming Formations of the Texas Gulf Coastal Plain. The Alabama discovery aids in correlation with the Texas localities and with Arikareean faunas of the Great Plains.

### Rocky Mountain Eocene floristic zones

On the basis of pollen stratigraphic sections with vertebrate-dated horizons, the Rocky Mountain Eocene has now been divided into five floristic zones by E. B. Leopold. The first zone, identified from the lower Golden Valley Formation of North Dakota is earliest Wasatchian in age, and is characterized by the presence of many Sentinel Butte (late Paleocene) forms in combination with a few key Eocene taxa (notably *Tilia*). The second zone is dominated by *Platycarya* pollen, and is marked by the first appearance of Eocene forms such as *Triumfetta*, *Cardiospermum*, and *Gunnera*. This zone, representing most of the Wasatchian (early Eocene) provincial age, has been found at a wide number of localities in northern and southern Wyoming, and overlies the first zone in North Dakota. The third zone, of lowest middle Eocene age, is dominated by *Lygodium* cf. *karlfussi*, and a host of key Eocene forms appear here, including *Ilex*, *Bombacaceae Cedrella*, and *Sapotaceae*. This stratigraphic zone overlies zone 2 in northern and central Wyoming, but its apparent absence at more southerly localities may be the result of broad sampling. The fourth zone

<sup>80</sup> U.S. Geological Survey, 1965, Geological Survey Research 1965, chapter A: U.S. Geol. Survey Prof. Paper 525-A, p. A11.

lies some distance above zone 2 in the Green River Formation, the Laney Shale Member in the Washakie Basin; it is, in part, of Bridger A (middle Eocene) age. The flora is an impoverished version of the zone 3 flora, and is typified by *Palmae*, *Alnus*, *Betula*, *Nyssa*, *Lomatia*, and rare *Coniferae*, *Platycarya* and *Rosaceae*. The highest zone 5, also found in the Washakie Basin, is of Bridger D through Uinta B and C(?) ages, and therefore encompasses much of late Eocene time. It is dominated by shrub elements such as *Rosaceae*, and contains abundant steppe elements, (*Ephedra*, *Sarcobatus*, *Chenopodiaceae*) and a few temperate hardwoods (such as *Eucommia*, *Ulmus*, *Pterocarya*, and *Betula*). The aquatic *Sparganium* is sporadically abundant.

Climatically, zones 1 to 3 represent subtropical floras and conditions of seasonal rainfall. Zones 4 and 5 show an increasing temperateness and a seasonally dry climate. The flora of zone 5 indicates inadequate rainfall to support true forest, and for the first time provides a floristic record transitional between the subtropical early and middle Eocene assemblages, and the dry temperate flora of Chadron (early Oligocene) age as recorded at Florissant, Colo.

#### **Miocene diatoms of Nebraska**

The Monroe Creek Sandstone contains two recognizable diatomaceous beds in the Pine Ridge area of Sioux County, near Crawford, Nebr., according to G. W. Andrews. The Monroe Creek Sandstone contains few vertebrate fossils, but is well dated by its stratigraphic position as the middle formation of the Arikaree Group. Its lower Miocene age is based on its position above the fossiliferous Brule Clay (Oligocene) and below the early Miocene Agate Springs fauna of the overlying Harrison Sandstone. The diatom assemblage of the Monroe Creek Sandstone contains several extinct species known previously only from the Wagon Bed Formation (upper Eocene) of Wyoming. It contains substantially fewer modern species than does the late Miocene diatom assemblage near Kilgore, Nebr. This diatom assemblage is stratigraphically important in that it contains the oldest known Miocene nonmarine diatoms from the Great Plains region of North America.

#### **New Cenozoic vertebrate finds on the High Plains**

G. E. Lewis (p. B137-B140) reported several significant discoveries of Cenozoic vertebrates brought to his attention by observant field men and laymen in recent excavations in Colorado. The first concerns a fossilized drove of peccaries (*Platygonus*), never before known from Colorado, found in a life assem-

blage buried in a Pleistocene sand dune and exposed in excavations for the Denver Juvenile Hall. In total, the assemblage included an old boar, an old sow, a young boar, a shote, and a suckling piglet.

Liaison with the construction crew on Interstate Highway 80S resulted in the discovery and excavation of a long-jawed mastodon skeleton, the largest of this kind yet discovered. Together with a fossil rodent jaw discovered by A. D. Elken (U.S. Dept. of Agriculture) and petrographic criteria, the evidence is conclusive that this wide belt of outcrops south of the South Platte River in Colorado represents the Ogallala Formation of Miocene and Pliocene age. This discovery, where the rocks for many miles had been mapped previously as White River Formation (Oligocene), extends the known distribution of the Ogallala nearly 50 miles north of previously recorded occurrences.

#### **Neogene floristics of the Arctic Slope**

Pollen analyses of independently dated Neogene samples from the Arctic Slope, Seward Peninsula, and adjacent areas by J. A. Wolfe indicate that tundra vegetation was not present on the Arctic coast during the Miocene. Instead, the forest was dominated by spruce, pine, hemlock, and a minor amount of broad-leaved trees (including elm). Middle Pliocene assemblages from the Seward Peninsula also represent a diverse conifer forest; plant megafossils contain such southern plants as white pine and snow-berry.

#### **Tertiary paleoclimates of Oregon and Washington**

A probable major climatic fluctuation occurred about 40 m.y. ago according to J. A. Wolfe. Analysis of fossil plants from the Puget Group of Washington and the Clarno Formation of Oregon of Eocene and Oligocene age indicate that the Eocene climate changed from tropical to almost temperate and then in the early Oligocene to marginally tropical. The cool assemblage in the Clarno Formation occurs in a paper shale; the collection includes flowers and insects, as well as well-preserved leaves and pollens.

#### **Pacific coast Miocene Foraminifera zonation**

Preliminary studies by R. L. Pierce of the type Mohnian and Delmontian Stages and regional biostratigraphic studies of other upper Miocene sections of California by the use of benthonic Foraminifera and fish indicate that Kleinpell's late Miocene concurrent-range zones probably require redefinition and revision. The Delmontian Stage of Kleinpell<sup>81</sup> is correlative with his Mohnian Stage on the basis of the occurrence of: (1) *Epistominella gyroidinaformis* (Cushman and Goudkoff) in the lower part of the



type Delmontian, (2) *Bolivina hughesi* Cushman (= *Bolivina sinuata alisoensis* Cushman and Adams of others), *Bulimina delreyensis* Cushman and Galliher, and *Etringus scintillans* Jordan in the upper part of the type Delmontian. (None of these species are known above the upper Mohnian in California.), (3) late Miocene megafossils in the Santa Margarita Sandstone, which lies with apparent conformity upon beds that are near and correlate with the upper part of the type Delmontian. Kleinpell's<sup>81</sup> *Bolivina obliqua* Concurrent-range Zone (Delmontian) overlaps the range of species characteristic of his subjacent *Bolivina hughesi* Zone in the type area of the Mohnian Stage and all other Mohnian zones at other localities in California. Many of the species characteristic of Kleinpell's<sup>81</sup> late Mohnian, *Bolivina hughesi* Zone, overlap both his subjacent *Bulimina wigerinaformis* Zone and his superjacent *Bolivina obliqua* Zone. Many of the species characteristic of his *Bulimina wigerinaformis* Zone overlap both his subjacent *Bolivina modeloensis* Zone and his superjacent *Bolivina hughesi* Zone. *Bulimina wigerinaformis* Cushman and Kleinpell and *Bulimina delreyensis* Cushman and Galliher have the same stratigraphic range and appear not to range above middle Mohnian in California.

#### First Paleocene in Gulf of Alaska region

Rocks of probable Paleocene age were identified for the first time in the Gulf of Alaska region, according to George Plafker. Several collections of leaves and one collection of marine mollusks, which were identified by J. A. Wolfe and W. O. Addicott, were obtained from a thick sequence of intertonguing marine and continental clastic rocks in the Saint Elias Mountains of the Malaspina district. The megafauna provides the first indication of marine rocks of Paleocene age from Alaska and occurs 20° north of the northernmost occurrence of Paleocene, larger marine invertebrates along the west coast of North America.

### OTHER PALEONTOLOGICAL STUDIES

#### Further studies of fur seals

The fur seals are separable from the sea lions by the presence of abundant underfur. No other morphologic character has been found that consistently distinguishes between these two subfamilies, and C. A. Repenning suggested that subfamily distinction is unreal.

Repenning recognized two genera of fur seals: the monospecific *Callorhinus* of the northern hemisphere, and the genus *Arctocephalus* largely of the southern

hemisphere. Except for underfur, some species of *Arctocephalus* show greater resemblance to some sea lion genera than they do to *Callorhinus*. As recognized by Repenning, *Arctocephalus* contains eight species which can be defined on the basis of features of skull and dentition. The South African population appears to be indistinguishable from the fur seal of southeastern Australia and Tasmania, and both are placed in one species. The Guadalupe fur seal of southern California and Mexican waters is very similar to the population living in the Juan Fernandez Islands, Chile, but a few differences suggest that separate species recognition should be maintained pending the availability of larger samples.

#### Palynological samples from the Alaska North Slope

R. A. Scott completed the processing of more than 2,000 palynological samples from cores taken from wells drilled on Naval Petroleum Reserve No. 4. Pollen, spores, and other palynomorphs from the 41 wells have been mounted on slides. Sets of these slides have furnished useful information to those interested in the geology of the Alaskan North Slope, where recent oil discoveries have been made. Slide sets may be borrowed from the Paleontology and Stratigraphy Branch at Denver, Colo.

### GEOMORPHOLOGY

#### Changes in channel morphology

R. P. Williams reported that data from 76 gaging stations throughout southern California were compiled from records covering a 50-year period in an attempt to present the nature of scour and fill under conditions not affected by manmade structures. Although stream-bed observations were measured during low-flow periods, the most significant changes, or those exceeding half a foot, were the results of intense storm periods. Of the 242 measurements taken under the conditions of significant change, 52.5 percent represented fill.

#### Overland flow on hillslopes

W. W. Emmett reported that the emphasis on hillslope studies has been shifted from the hydraulics of overland flow to the erosional and sedimentation characteristics of overland flow and their importance to the general shape of hillslopes. A technique has been developed to provide geometrical descriptions of the shape of hillslopes in various climatic and lithologic environments. Preliminary analyses of hillslope profiles indicate that the convexity and concavity of hillslopes can be related to the relief ratio of the slope.

<sup>81</sup> Kleinpell, R. M., 1938, Miocene stratigraphy of California: Tulsa, Okla., Am. Assoc. Petroleum Geologists, 450 p.

The field data are in general agreement with random-walk statistical models, and concave slope segments also show an analagous trend to concave river profiles.

#### **Archeological studies furnish information on erosion and deposition cycles**

Field studies of the Holocene epicycles of erosion and deposition in the lower San Juan drainage in the Southwest, conducted by Deric O'Bryan, M. E. Cooley, and T. C. Winter, and sponsored by the International Hydrological Decade 1967-69, have been terminated. Archeological evidence suggests that the period of accelerated erosion which began locally in the 1880's continues to date. The trash mound of a Pueblo II-III (approximately A.D. 1050-1200) surface ruin in Long House Valley, the southernmost tributary of Laguna Creek which is the main western contributor to Chinle Wash, was bisected by an arroyo about 12 feet deep by 1966; the side of a corrugated jar was exposed in the northern vertical wall of the arroyo. A year later the jar had been "weathered" out and washed away. In 1967 human leg bones (tibias and femurs) were noticed protruding from the southern bank of the arroyo at the same site. Erosion had removed all trace of the burial by 1969.

A prehistoric coursed-stone check dam, constructed no later than the 13th century, was noted several hundred yards north of the above-mentioned site in 1965 (and a picture was taken of the intact structure) at the headward limit of a small arroyo. The dam was breached by 1967, and obliterated by 1969 (when the site was again photographed). The headward migration of the small arroyo had extended over 100 feet.

Confirmatory evidence of continuing erosion is provided by a sediment-choked cave in Walker Creek, a large eastern tributary of Chinle Wash, about 60 airline miles east of Long House Valley. First observed in 1965, the maximum depth of alluvium at the eastern end of the cave was 34 feet. A Basker Maker III horizon (7th and 8th centuries) is exposed 3 feet above the sandstone floor of the cave, the floor of which is about 10 feet above the present stream channel. A Pueblo II-III occupation layer is exposed 4 feet above the earlier horizon and apparently separated by a stratum of archaeologically sterile sediment.

The cave was revisited annually through 1968. Each year, floodwaters had undercut the cave fill sufficiently to expose an altered face to parts of the deposit. This suggests that local erosion has been more active in the past 90 years than during any other period of comparable time since the 7th century.

Most archeologists concerned with the Southwest

have placed emphasis on climatic stress, probably drought as reflected by impaired tree growth, as the dominant reason for the exodus of the Pueblo Indians from the San Juan drainage. During the study 26 contemporaneous Mesa Verde type ruins dating to the second half of the 13th century A.D. along the main channel of the San Juan River from Farmington, N. Mex., west or downstream to the mouth of Chinle Wash, Utah, were located and partly described. Studies of other equivalent known sites east of the area of study, late Pueblo III ruins once occupied by Indians of the Mesa Verde culture complex, near Aztec and Bloomfield, N. Mex., lead to the same conclusions but are not included in the following discussion.

All 26 sites under consideration were built on the stream channel edge where defensible access to a dependable water supply was assured, as well as an unobstructed view of irrigable land. All sites, except isolated towers, are enclosed by thick masonry walls on the land-approach sides; tiers of rooms, subterranean ceremonial chambers (kivas), and courtyards congest the ground between the fortresslike walls and the river channel. Another characteristic of all 26 sites is the paucity of cultural remains, suggesting that the structures were only just completed, or nearly completed, before they were abandoned.

Several comparable and contemporaneous fortified or defensible ruins once occupied by Indians of the Kayenta culture were found in the upper Laguna Creek area, Arizona. It is estimated that about 15 people were affiliated with each kiva (a conservative figure as only the men used the subterranean ceremonial chamber). The sites suggest that over 1,500 Mesa Verde Indians plus several hundred Kayenta contemporaries were "on the run" from predatory nomads—and not primarily from drought conditions as they probably moved on to the less watered regions centered on the Zuni and Hopi villages.

### **GROUND-WATER HYDROLOGY**

The broad spectrum of research in ground-water hydrology reflects the dynamic growth of this relatively young branch of the earth sciences. Interaction between research and field application stimulates basic research into principles, concepts, and processes and applied research in field technology identifies the deficiencies in modeling and simulation of geohydrologic systems. The following summary statements cover selected examples of research with particular reference to current field investigations.

### Artificial recharge

At Orlando, Fla., field tests were run by W. F. Lichtler on a hydraulic-connector well which was installed to conduct water from a shallow water-table zone across dense clay layers to the basal part of the hole which is open to limestones of the Floridan aquifer. The procedure should lower the shallow water table and recharge the Floridan aquifer, which is the principal source for water supplies in central Florida.

Relatively salty water in the Floridan aquifer in easternmost Orange County, Fla., has limited the use of several wells which supply water for the city of Cocoa. In the city's well-field area, natural recharge of the Floridan aquifer is retarded by intervening layers of marl and clayey sands. In a study to determine the feasibility of storing excess fresh water underground during periods of low demand, so that higher quality water will be available during periods of peak demand, C. H. Tibbals found that fresh water with 20 mg/l chloride content is being recharged through a supply well which normally yields water with more than 400 mg/l chloride content. Preliminary analyses after four injection and withdrawal cycles indicate that a buffer zone is being established between the fresh and salty water and that greater amounts of recharge water are recovered with each successive cycle. However, the cavernous nature of the limestone along with its very high permeability tend to encourage greater mixing of fresh and salty water than would be expected from a more homogeneous aquifer of lower permeability. This greater mixing of fresh and salty water inhibits the formation of a buffer zone with a thin zone of diffusion and apparently has lowered the efficiency of the recovery of recharge water during these first four injection withdrawal cycles.

### Surface geophysics

A number of surface geophysical surveys related to ground-water investigations were conducted by A. A. R. Zohdy in Arizona, Idaho, and Utah. Studies in Idaho indicated great thicknesses of materials overlying basement rocks. Basalt of the Snake River Group was estimated to be as thick as 3,000 feet near Minidoka, Idaho, and was underlain by sedimentary rocks. The depth to basement was estimated to be between 13,000 and 17,000 feet at one sounding station in this area. About 6,000 feet of low-density sediments was detected by gravity and seismic-refraction surveying in the Malad Valley, Idaho.

Deep electrical resistivity soundings made near Bowie, Ariz., indicate that a major clay layer separates the principal aquifers of the area and that the

clay layer can be mapped successfully by the resistivity method. The artesian aquifer beneath the clay has a significant thickness, about 1,000 feet, and is underlain by clay or by saline water.

A gravity survey of Cache Valley in Idaho and Utah, made by D. L. Peterson and S. S. Oriel (p. C114-C118) as part of a water-resources study, indicated that a large complex gravity anomaly coincides with Cache Valley and reveals a complex basin structure. The thickest Cenozoic strata, 7,000 to 8,000 feet, occur in two fault-bounded troughs near the Idaho-Utah State line. These troughs are separated by a basement high which is indicated by high gravity values that extend northward into the Bannock Range. A belt of high gravity values extends southwestward from Mount Smart to Lewiston, suggesting a buried block of Paleozoic rock.

### Salt water-fresh water relations

Akio Ogata and J. M. Cahill reported that preliminary test data of a two-fluid flow system (salt-fresh water) in a porous medium indicate good agreement with the dynamic theory that predicts the position of the two-fluid interface. Salt-concentration distribution data along the contact zone were obtained by use of a standard, removable conductivity probe. The probe itself is made of hypodermic needles which are inserted through raw rubber patches on the side of the model. Calculation of the dispersion coefficient from the approximate expression, if one takes into account only the diffusion perpendicular to the flow lines, indicates that the dispersion coefficient is about an order of magnitude too large as compared with some published data. Further tests are now being conducted to verify the present data and to determine whether assumptions made in development of the theory are valid.

### Hydrology of clay

The field and laboratory evaluations of the hydraulic diffusivity of a confining bed were completed by R. G. Wolff. The field approach consisted of measuring the head change within the clay, that resulted from the pumping of an overlying aquifer, by placing piezometers equipped with differential pressure transducers at different depths in the clay. The laboratory evaluation consisted of standard consolidation testing coupled with an independent hydraulic-conductivity evaluation. Diffusivity-results obtained from the field and from the laboratory for the natural effective load were in good agreement.

Analyses of surface-strain measurements made in the vicinity of the pumping well suggested that

observed, negative pore-pressure changes, which occurred in the clay upon starting the pump, are probably the result of viscous drag in the pumped aquifer; the viscous drag is transferred by shear to the underlying clay. A conceptual model which envisions the transference of such shear across one or more confining layers may account for some previously unexplained reverse water-level fluctuations.

#### **Velocities of radionuclides at the Amargosa tracer site, Nevada**

Derivation of a mathematical model to account for longitudinal mixing in a finite flow system at the Amargosa tracer site, Nevada, was completed by D. B. Grove. This model integrated the 1960 work of J. A. Da Costa and R. R. Bennett for ideal flow in a two-dimensional system and the 1962 work by Howard Brenner for dispersed flow in finite columns.

The mathematical model analyzes the dispersion through a flow tube bounded by adjacent streamlines in a dynamic-potential field between a recharge-discharge pair of wells. The time-dependent breakthrough curve for a tracer injected into the recharge well is calculated for each flow tube. The effect is summed over the entire system, resulting in an integrated breakthrough curve. The curve from the mathematical model is matched to the breakthrough curve for the field data in order to arrive at the magnitude of such controlling variables as porosity and a dispersion constant.

### **SURFACE-WATER HYDROLOGY**

Research in the field of surface-water hydrology is directed toward improvement in the ability to furnish information on the occurrence and characteristics of surface-water. Current emphasis is on such important problems as data for reservoir management, the time of travel and dispersal rate of contaminants, including heat, and on methods of synthesizing streamflow information.

#### **Mechanics of flow and heat transport**

Problems of thermal pollution and heat transport are of prime current interest in studies of the mechanics of flow.

In a 20-mile reach in Dan River, N.C., R. M. Burton studied the dispersion of hot water effluent at different seasons of the year and at three different discharges. It was found that the higher the stage, the farther downstream is the point where the lateral water temperature reaches equilibrium. Less than 30 percent of the added heat is dissipated to the atmosphere in the 20-mile reach.

R. S. McQuivey and T. N. Keefer used laboratory models at Fort Collins, Colo., to determine temperature distributions and the spread of heat below powerplants. A neutrally buoyant salt solution was used in a noncirculating flume, with 3 boundary roughnesses, 3 nozzle sizes, and 4 jet Froude numbers for each boundary roughness. The flow was mapped completely by velocity and turbulence profiles and by defining space-time correlations in the lateral, vertical, and longitudinal directions. The methods developed here allow the diffusion coefficients and temperature distributions to be predicted from knowledge of the statistical properties of the flow field, the jet strength, and the physical characteristics of the dispersant.

A computer program to simulate the transport and dissipation of heat has been checked by Nobuhiro Yotsukura, using thermal data collected in the Potomac River near Dickerson, Md., in 1969. The pronounced lateral nonuniformity of temperature has been simulated with an error of  $\pm 1^\circ\text{C}$ . However, it has also been found that the lateral distribution of heat in the Potomac can be simulated satisfactorily by analytical use of the Fickian diffusion equation. Similar satisfactory results by the diffusion equation have been obtained for dye data for the Missouri River in 1967 and for the Atrisco Feeder Canal in New Mexico in 1966. The analytical method requires less data than the computer solution.

E. J. Pluhowski investigated the effect on stream temperature of a change in vegetative cover along the channel. The lower end of Colvin Run near Reston, Va., was stripped of its natural cover during the course of a highway project. The difference in afternoon stream temperature between the upper and lower ends of a 1,200-foot reach was found to vary between  $3^\circ$  and  $4^\circ\text{C}$ . The higher temperatures at the lower end are attributed to the greater absorption of radiant energy in the unshielded channel. The effect on temperature is most pronounced in summer and is least evident in winter when insolation is at a minimum.

Measurements of the energy spectrum of the longitudinal component of turbulence were made in a 10-inch-diameter circular conduit by H. J. Tracy. The walls of the conduit were smooth for the first measurement and artificially roughened for the second measurement. A comparison of these spectra indicates that the distribution of the relative intensity of the turbulence is not greatly different for the two conditions of boundary roughness.

#### **Streamflow generalization**

As part of a nationwide study of the streamflow-data program, all district offices are developing generalized

multiple-regression equations that relate streamflow characteristics of all kinds to basin and climate characteristics. These relations provide a means of furnishing streamflow information of the type that is used for planning and design purposes, for ungaged streams. The streamflow characteristics include mean annual and monthly runoff, indices of flow variability, peak flows, low flows, and points on the flow-duration curve. Because the development of such relations has now become a routine procedure, only such studies are reported that deal with unusual circumstances or represent improvements on present methods.

In Wisconsin, D. H. Conger found the hydrologic soils index, based on U.S. Soil Conservation Service soils classifications, to be closely related to floodflows. A relation was found between the percentage of forested area and the soils index. The relation between the two is being studied to find an index that is simpler to evaluate than the soils index.

In Puerto Rico, M. A. Lopez and F. K. Fields found that, except in limestone areas, floodflows can be estimated by relation to drainage area and a precipitation index. Most basins are geometrically similar; thus other basin characteristics are closely related to drainage area and do not help to reduce the error of estimate of flood peaks.

Relations between basin lag time, area, basin mean length, and slope were found by V. B. Sauer for streams in Louisiana. The lag time and basin size can then be used to convert to a unit hydrograph for an ungaged site. Sauer found that the lag time varies with the size of storm, and attributed this to the variable travel distance of a meandering stream within a straight flood-plain valley.

In arid regions, mean annual runoff may not be adequately correlated with the usual basin and climate characteristics. However, previous studies in Western States indicated that the shape of the low-water channel in streams with erodible beds is related to the mean annual runoff. E. R. Hedman made a detailed study in Kansas and arrived at a relation between mean annual runoff and the width and average depth of cross sections between bars and berms. The relation has a standard error of estimate of about 40 percent.

In the Rock River basin in Wisconsin, W. A. Gebert developed a generalized relation between low-flow characteristics and basin characteristics. Of the 13 basin characteristics in the study, drainage density, permeability of the glacial deposits, and drainage area were found to be the most significant. The equations developed had a standard error of estimate of about 55 percent. The results provide a useful method for

estimating low flows in ungaged areas and also illustrate the close relationship between geology and low flow.

#### Synthesis of streamflow records

E. J. Gilroy studied the extension of a record of a variable  $y$  of length  $n_1$  by means of  $n_2$  regression estimates of  $y$  obtained from  $p$  other variables which along with  $y$  follow a  $(p + 1)$ -dimensional normal probability law. He derived the sampling variance of an estimate of the variance of  $y$  obtained from the extended record and found the result to be a multivariate generalization of a result found by N. C. Matalas and Barbara Jacobs in 1964.

Synthesized records were used by S. P. Sauer in studying low-flow probabilities in the Concho River basin in west-central Texas. He found the 1962-68 drought to be a hydrologic event having an average recurrence interval in excess of 200 years. The very low runoff during this period was primarily due to a lack of adequate rainfall rather than depletions of flow by land and water use. Long-term streamflow records were adjusted for depletion by land and water use, resulting in a first-order stationary time series of annual runoff. The statistics of the adjusted annual runoff samples were used to simulate 1,000-year record periods, using a first-order Markovian generating process with a log-normal probability function. These 1,000-year simulated records were used to develop deficiency-probability distribution curves for 2-, 3-, 5-, 7-, and 10-year flows.

Flood hydrographs are needed for taking storage into account in the design of culverts in small drainage basins in Wyoming. G. S. Craig, Jr. (D238-D243), developed a composite-mean, dimensionless hydrograph from observed hydrographs on 14 drainage basins of less than 11 sq mi. This was used to produce synthetic hydrographs that compare closely with observed runoff events on other small basins in Wyoming and New Mexico. Peak discharge in cubic feet per second and runoff volume in acre-feet are the data needed to produce a synthetic hydrograph from the composite hydrograph.

#### Time of travel

The time of travel of solutes through stream channels and their dilution in a downstream direction is important because of the hazards of accidental spills or planned release of pollutants.

Using data from over 500 streams where time-of-travel studies had been made, F. A. Kilpatrick related the amount of Rhodamine B, BA, and WT fluorescent

dyes necessary for slug injection into streams having widely different flow characteristics. He found that for Rhodamine B and BA the amount increases significantly with reduced stream velocities owing to dye loss. For this reason a separate dye dosage relationship was developed for the newer Rhodamine WT dye. He found that because of lower dye losses, this dye was generally more economical despite its greater initial cost. On larger streams, the use of Rhodamine WT dye was found to yield monetary savings in excess of 50 percent, as compared with Rhodamine B and BA.

It has been found that manpower costs connected with sampling amount to 80 to 90 percent of the total cost of time-of-travel and other dye-tracer type studies. For this reason Kilpatrick has developed a floating automatic dye sampler intended to greatly reduce such costs, as well as improve data collection. The unit is anchored or otherwise secured in the river, estuary, or other body of water being investigated with a dye tracer. Mounted vertically and partially submerged are 24 spring-powered hypodermic syringes which may be set to draw in a sample at intervals ranging from 10 to 120 minutes. The unit has been tried successfully on several streams in Louisiana and Virginia, yielding not only monetary savings, but morale and safety benefits, as manual sampling at night and during inclement weather has been eliminated. Because of economies realized the unit may point the way to increased use of time-of-travel studies.

The time of travel of the peak concentrations of water-carried dye on the Batten Kill in eastern New York was found by H. L. Shindel to cover a range of velocities from 0.14 to 2.03 fps. Low velocities were found associated with low aeration coefficients and high velocities with high aeration coefficients. The aeration coefficients varied between 0.18 and 5.28. In general, low velocities and aeration coefficients occurred in those subreaches that had artificial controls on the flow. In line with these findings, F. B. Gay found that, on the Housatonic River in southeastern Massachusetts, traveltime for peak concentration of a contaminant has decreased twofold to fourfold on reaches of the river within which three small dams failed in 1968 and 1969.

W. J. Shampine found that the flood wave generated by power releases from Toledo Bend Reservoir on the Sabine River in Louisiana traveled 1.7 times faster than the water particles in the channel downstream from the dam. Traveltime of the water particles was measured by fluorescent dye tracers.

### **Reservoirs and storage**

Reservoirs constructed within a basin, whether large or small, may have a significant effect on the channel morphology or the hydrology of the basin. D. G. Frickel examined the effect of the construction of 141 small detention reservoirs between 1954 and 1967 in the Willow Creek basin near Glasgow, Mont. He found that regulation of the flow has apparently changed the channel regime; at one point on the main channel the width decreased from 80 to 53 feet during this period.

W. H. Kirby (U.S. Geological Survey) and Charles Revelle (Cornell University) have developed a new kind of reservoir operating rule, the linear decision rule (LDR). This method uses the difference between the initial reservoir content and a seasonal decision parameter to make a firm release commitment for the coming season. The reservoir capacity required to keep storage and release commitments within stated limits with specified reliability can be minimized or, if the capacity is given, performance measures such as expected or minimum reliable releases can be maximized. General qualitative arguments and an idealized example indicate that the LDR may be better than conventional target-hitting rules when water users are free to attune their activities to the anticipated supply. In a more realistic simulation study, the LDR performed better than the currently used operating policy.

J. F. Turner, Jr., has analyzed within-year draft-storage data for 11 long-term gaging stations in North Carolina to determine the feasibility of deriving relationships for estimating critical runoff periods. The data used in this analysis consist of (a) draft rates, (b) storage required to maintain, (c) critical periods, and (d) 7-day, 2-year minimum discharge. The analysis indicates that a relationship does exist between the critical period (dependent variable) and the draft rate (independent variable) for observed or estimated values of the 7-day, 2-year minimum discharge parameter, although the relationship is of a complex (non-linear) log form.

### **Computation of roughness parameter**

In connection with a study for the U.S. Atomic Energy Commission of the transport of radionuclides in the Columbia River and estuary, G. A. Lutz computed values of the roughness parameter of the river at the Beaver Army Terminal, Oreg. (about 50 miles from the mouth) from a one-dimensional transient-flow model. The values ranged between 0.0248 and 0.0301 and correlated with the mean daily discharge. For relatively low flows, the values were high; for the

high flows, the values were low; and for the intermediate flows, the values varied progressively between the two extremes.

## CHEMICAL AND PHYSICAL CHARACTERISTICS OF WATER

### Water-quality relationship with aquatic biota

P. A. Kammerer, Jr., began a study of Nederlo Creek, near Prairie du Chien, Crawford County, Wis., to determine the effects that the construction (in 1972) of a multipurpose reservoir in a small drainage basin (10 sq mi) will have on water quality and aquatic biota interrelationships. Preconstruction data include collection and identification of algae and documentation of water-quality conditions.

Water in the basin is predominantly calcium-magnesium-bicarbonate type and has a dissolved-solids concentration of around 250 mg/l at base flow. The stream is quite productive and is able to support a substantial crop of aquatic plants (primarily water-cress) and diverse algae populations. Dense growths of filamentous algae, primarily *Oscillatoria*, *Cladophora*, and *Spirogyra*, are present in the headwaters regions of the stream in the spring and summer months. These algae beds are generally destroyed during floods but recover fairly rapidly. Several genera of green algae and diatoms are found in the streams and springs, but *Oscillatoria* is usually the only blue-green alga present.

Dissolved-oxygen concentrations during critical summer months do not drop below 7 mg/l at night and reach daytime highs of 13 to 14 mg/l. These values represent a range of about 80 to 130 percent saturation at normal summer water temperatures.

### Temperature of streams

Using multiple-regression techniques to study stream temperatures in Washington State, M. R. Collings found that the orientation of the stream has an interesting relation to the monthly standard deviation of daily stream temperatures. Beginning in April (just after the vernal equinox) and continuing for May, orientation is a highly significant independent variable, and then in September, as autumn begins, the orientation coefficient again becomes highly significant. During the remainder of the year the orientation is not a significant variable.

### Water quality of streams and ground water

In a reconnaissance of the progress of self-purification of a 136.5-mi reach of the San Antonio River, Tex., Jack Rawson found that the critical part

of the reach studied during the low-flow period June 17–19, 1969, extended from mile 203.0 to mile 175.5. The dissolved-oxygen content of water in this 27.5-mi reach averaged about 5.0 mg/l, and the dissolved-oxygen deficit averaged about 3.0 mg/l. The time-weighted averages of other water-quality parameters or constituents at mile 203.0 were as follows: biochemical oxygen demand (BOD), 14 mg/l; total nitrogen, 7.6 mg/l; and total phosphate, 9.7 mg/l. Dilution of waste effluent, supplemented by bacterial stabilization of organic matter and algal uptake of nitrogen and phosphorus, resulted in an increase in the dissolved oxygen and a decrease in the dissolved-oxygen deficit, BOD, and concentrations of total nitrogen and total phosphate at downstream sites. The time-weighted averages of these water-quality parameters or constituents at mile 66.5, the lowermost site in the area studied, were as follows: BOD, 1.8 mg/l; dissolved oxygen, 7.2 mg/l; dissolved-oxygen deficit, 0.7 mg/l; total nitrogen, 3.4 mg/l; and total phosphate, 2.5 mg/l.

E. C. Mallory, Jr., and P. R. Barnett determined, by spectrographic analysis, the minor-element concentrations in more than 90 spring and artesian-well samples collected along the eastern slope of the Colorado Rockies. Aluminum, barium, boron, iron, lithium, and strontium were found in the majority of the samples. Copper, nickel, silver, titanium, zinc, zirconium, cobalt, and cesium were found in a significant number of samples, and arsenic, cadmium, bismuth, lanthanum, and vanadium were detected occasionally. Antimony, gallium, germanium, tin, ytterbium, and yttrium, although tested for, were not detected in any of the samples collected.

Generally a good correlation was found between the occurrence of a minor element in the spring water of an area and the existence of known, commercially important deposits of that element. In some thermal springs it was possible to compare present-day temperatures of the water with temperatures observed more than 50 years ago. Very little temperature difference was noted, although there is some evidence to indicate a slight decrease in the dissolved-solids content.

V. J. Janzer reported that radiochemical analyses of these same samples disclosed a wide range of radiochemical content. Uranium concentrations ranged from less than the detection level of 0.01  $\mu\text{g/l}$  to 120  $\mu\text{g/l}$ , whereas radium concentrations of less than 0.01 pCi/l to a maximum of 260 pCi/l were found. Gross alpha and beta determinations were made on all samples as a general indication of the level of overall radioactivity of the samples.

A statewide assessment in Florida of historical pH



data, by M. I. Kaufman, indicated that the carbonic system is the principal control of the pH of most natural water in the State; pH values range from 4.0 to 8.5. Low pH relates to  $\text{CO}_2$  and organic acids produced during decomposition of organic matter, and high pH relates to surficial carbonate terrane or alkaline ground-water inflow. During low-flow periods, the stream pH approaches that of the contributing aquifer, whereas in parts of the State, during high-flow periods the pH approaches that of a  $\text{CO}_2$ -organic acid rich environment. Florida's surface water exhibits distinct regional variations in pH extremes, especially in regard to minimum values; the distribution pattern of these values provides insight into the hydrologic flow system and emphasizes pertinent environmental controls on water quality. Kaufman's report is one step toward the portrayal of water-quality data for Florida on a regional basis.

E. F. McCarren reported that the quality of water in the main body of Neshaminy Creek, Pa., is suitable for irrigation and recreation and for domestic and industrial use after moderate treatment. However, the dissolved-solids load in Neshaminy Creek has increased by 57 percent since the late 1940's. At Langhorne the concentration ratios of calcium and magnesium, sulfate and nitrate to the total dissolved solids have been nearly constant, whereas the sodium and chloride ratios have significantly increased. Although the precise cause for the increased concentrations of sodium and chloride in the stream has not been established, it can probably be related directly to the urbanization trend of Bucks County and the increased use of Neshaminy Creek water.

Water year 1969 was a wet one for the Truckee River. The stream originates in the Sierra Nevada at Lake Tahoe, along the California-Nevada State line, and empties into Pyramid Lake, Nev., a topographically closed desert lake about 60 miles to the northeast. According to P. A. Glancy and A. S. Van Denburgh, streamflow at the farthest downstream gage, about 10 miles above Pyramid 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-year record, is only about 245,000 acre-ft.) The sediment load was estimated at about 650,000 tons and represents about 270 acre-ft of eroded material upstream. The maximum measured concentration of suspended sediment during the year was 2,400 mg/l on January 20, 1969. The solute content of streamflow at the gage was monitored between mid-January and September. The water

ranged from a calcium-bicarbonate type with a specific conductance of about 100  $\mu\text{mhos}$  (during high flow, April-June) to a type dominated by sodium, bicarbonate, and to a lesser extent chloride, with a conductivity of 600 to 700  $\mu\text{mhos}$  (during low flow, August-September). The solute load carried into Pyramid Lake during the year was estimated at 140,000 tons, of which about 30 percent consisted of principal dissolved components of the lake (sodium bicarbonate, expressed as  $\text{Na}_2\text{CO}_3$ , and sodium chloride).

Data obtained by I. H. Kantrowitz (r2385) from an exploratory water well, drilled on a barrier island 3,000 feet south of the easternmost extent of the Maryland-Delaware State boundary, indicated that fresh water occurs to a depth of 480 feet below mean sea level. A multiple-point electric log of the pilot hole showed that ground water becomes progressively more saline with depth. A major fresh-water aquifer (Miocene) occurs between 305 and 460 feet. The dissolved-solids content of water sampled from the aquifer between 358 and 368 feet was 190 mg/l. A very fine grained sand unit below the aquifer (460 to 470 feet) contained water with 800 mg/l of dissolved solids. Formation water sampled between 703 and 713 feet had a dissolved-solids content of 5,240 mg/l.

#### Statistical analysis

S. M. Rogers reported that statistical analysis of water-quality records for 1929-57 delineated areas of similar water quality, such as the Piedmont, Blue Ridge, and Coastal Plain provinces of Virginia, in which a general formula will adequately define the water quality for many purposes. Comparison with recent (1968 water year) data from the same provinces shows that a slight adjustment for some constituent ions may be necessary but not for all ions. A single-index parameter may be used for monitoring water quality on streams in these areas.

#### Pore-water solutes

R. V. James and Jacob Rubin, using short, vertical columns of glass beads, investigated dispersion of solutes during miscible displacement of one electrolyte solution by another. It was found that the system studied has to be treated as a two-layered one, with the glass beads being considered as one layer and the passages in the bottom cap of the apparatus being taken as another layer. For relatively slow flows, the two-layer model yielded theoretical results which agreed well with the experiment. It was also found that theory will not be obeyed if the density ratio of the displacing solution to the displaced solution exceeds 1.0001.

### **Humic acids**

R. L. Wershaw and D. J. Pinckney developed a method for characterizing humic acids in soils and water. The humic acid is first fractionated by column chromatography and then the sizes, shapes, and weights of the various molecules present in each of the fractions are measured by low-angle X-ray scattering.

R. L. Malcolm found that the nitrogen content of terrestrial fulvic and humic acids, 2 percent and 3 percent respectively, are relatively constant and independent of the geographical source of the organic materials within the United States. The nitrogen content of humic and fulvic acids from river sediments tend to be dependent upon the amount of nitrogen in the water or may be an index of nitrogen pollution. For example, humic acid from the Mississippi River contains 7.5 percent nitrogen. Therefore, entirely different decomposition mechanisms may occur in aquatic systems than occur in terrestrial systems.

## **RELATION BETWEEN SURFACE WATER AND GROUND WATER**

### **Infiltration rate related to streamflow**

Pumping tests at five sites in glacial-outwash material adjacent to the Scioto River near Piketon, Ohio, were made at times of different stream discharge. Analysis by S. E. Norris (p. D262-D265) indicated that the unit rate of infiltration of river water to the aquifer varies directly with stream discharge and velocity. The evidence suggests that higher flows clean the streambed and increase its permeability. This relation between stream discharge and infiltration rate is important in that it permits the use of long-term streamflow records as an additional element in the design of induced infiltration facilities at this site, and it may be applicable to a large part of the stream-aquifer system in the lower Scioto River valley.

### **Aquifer diffusivity by flood-pulse method**

Significant differences in aquifer diffusivity among 10 sites in the Ohio River alluvial aquifer in Kentucky were reported by H. F. Grubb and H. H. Zehner from preliminary analysis of a flood wave on the Ohio River in 1970. Distances of 700 feet to 1,000 feet between a reference well used to observe river stage and a well used to observe aquifer response seems to provide adequate information for evaluating the diffusivity of this aquifer by the flood-pulse method. A qualitative evaluation of the hydraulic connection between the Ohio River and the alluvial aquifer can be made from the data.

### **Hydrograph separation**

A method for determining when river water moves to bank storage and returns to the stream in response to a flood was developed by J. F. Daniel, L. W. Cable, and R. J. Wolf (p. B219-223). Ground-water gradients determined in a profile of observation wells are used to index rates of inflow and outflow. The time when return flow is complete is found on the basis of equivalent volumes of water exchanged between the stream and aquifer. Application at a field site on the White River in central Indiana produced results consistent with theoretical concepts.

## **SOIL MOISTURE**

Continued progress has been made in studies of the character and dynamics of the unsaturated zone. Investigations completed during the year yielded results regarding (1) a method of estimating steady-state evaporation from layered soils, (2) three-dimensional study of the movement of water in the unsaturated zone, (3) permeability of the unsaturated zone to air, and (4) the effects of contour furrowing of rangeland on runoff, sediment yield, and plant growth.

### **Steady-state evaporation from layered soils**

C. D. Ripple, Jacob Rubin, and T. E. A. van Hylckama reported that the approximate method developed by them for estimating steady-state evaporation from bare playas was extended to areas in which the soils are layered and flow is affected by water-vapor transfer. Predictions made by this method were compared with field data from the U.S. Geological Survey lysimeters at Buckeye, Ariz., and satisfactory results were obtained.

### **Computer study of three-dimensional flow in unsaturated soil**

The infiltration of water into initially dry, horizontal soil cylinders has been studied both theoretically and experimentally by Jacob Rubin, P. C. Doherty, and C. D. Ripple. The cylinders were arranged so that the flow was three-dimensional and axially nonsymmetric owing to the effects of gravity. A computer-based numerical analysis yielded results which qualitatively agree with the experimental data. Quantitative comparison will be made when appropriate parameter data are obtained.

### **Use of change in air pressure to determine permeability of the unsaturated zone to air**

E. P. Weeks and M. L. Sorey have determined the relative permeabilities of layers of material in the unsaturated zone at several sites in the Western United

States. These permeability values have been obtained by measuring the lag in air pressure change at depth as atmospheric pressure changed at the surface, and by analyzing the data with analog and digital models. Permeabilities thus determined compare favorably with air permeabilities of cores of material obtained at the sites. However, hydraulic conductivities determined from the air permeabilities are much higher than those determined from core analyses, a difference due probably to the hydration and expansion of interspersed clay particles in the unsaturated material as water was added.

#### Effects of contour furrowing of rangeland

In a continuing study at Badger Wash, an experimental watershed near Grand Junction, Colo., G. C. Lusby found that over a 5-year period, contour furrowed rangeland produced only 27 percent as much runoff and 9 percent as much sediment as similar unfurrowed rangeland. The measurements were begun on two adjoining drainage basins in 1965, at which time one of the basins was furrowed with a road grader. In each alternate furrow, earth barriers were placed at intervals of 10 feet.

Water added to the soil by the presence of furrows has caused no visible increase in the quantity or vigor of plants adjacent to the furrows. The water apparently percolates downward from the bottoms of the furrows and is beyond the reach of plants. Plants in the area are primarily grasses with some intermixed shrubs.

### EVAPOTRANSPIRATION

Evapotranspiration is the sum of transpiration of water by plants and evaporation of water from the soil, water, snow, plants, and artificial surfaces. Evapotranspiration uses nearly 75 percent of the 30-inch average United States precipitation, nearly all the precipitation in the arid regions, and approximately one-third of the precipitation in the more humid regions. The quantity and rate of evapotranspiration is largely determined by the availability of water, available energy, and the transport of water vapor from the evaporating surfaces.

The rate and quantity of evapotranspiration is important in water-resource planning, which includes prediction of water supplies available for agriculture and municipal usage, estimation of drought incidence, and the designing of storage reservoirs and conveyance systems. Investigations of evapotranspiration reported include studies of (1) evapotranspiration by phreatophytes, (2) evapotranspiration in closed basins, (3) evaporation from lakes and reservoirs, and (4) evapo-

ration reduction by a floating cover of polyethylene foam.

#### Evapotranspiration by phreatophytes

Estimates of evapotranspiration by tamarisk brush and cottonwood trees were made by E. P. Weeks and M. L. Sorey for two small plots in bottomland along the Arkansas River in southeastern Colorado. For these estimates, the ground-water component was estimated by measuring water levels in arrays of five wells and introducing the data into a finite-difference approximation of the ground-water flow equation. The soil-moisture component was estimated by measurement of soil-moisture storage from samples and by neutron moisture-measuring techniques. The estimates thus obtained, agree well with estimates made by extrapolating data from other areas on the basis of meteorological factors.

During 6 years of observation of water use by saltcedar conducted in a battery of evapotranspirometers (tanks) T.E.A. van Hylckama<sup>82</sup> showed that the quantity of water used depends not only on the depth of ground water, but also on the salinity of the soil moisture. Saltcedar thickets thinned out to 50 percent of their original stand use nearly as much water as does a control population of saltcedar in tanks if the water is of good quality. Making a vegetation survey, and then extrapolating water use as measured in tanks to a 100-percent density can lead to serious overestimation. Thinning and cutting are ineffective methods of saving water. The assumption that phreatophytes always transpire at a potential rate is not sustained by the facts. With a water table at 12 feet (not unusual along dry riverbeds) saltcedar may still thrive but use comparatively little water, and claims as to the quantity of water potentially saved by their eradication could well be overestimated.

Additional study of the influence of atmospheric pressure on water levels in evapotranspirometers (tanks) by van Hylckama showed that in bare tanks or vegetated tanks that are not transpiring the fluctuation is closely correlated with diurnal and semidiurnal atmospheric fluctuations. The barometric efficiency is about 40 percent. Causes might be air bubbles in the saturated zone or the flexibility of the plastic lining of the tanks. On vegetated tanks that are transpiring, the water-level and barometric curves are out of phase. If the former are corrected for barometric fluctuations a curve appears that represents the hourly rate of water use.

In the semiarid zone of the southwestern United

<sup>82</sup> van Hylckama, T. E. A., 1970, Water use by saltcedar: Jour. Water Resources Research, v. 6, no. 3, p. 728-735.

States some 60,000 km<sup>2</sup> near washes and along rivers are covered by a dense growth of riparian or phreatophytic vegetation, consisting very often of pure stands of saltcedar (*Tamarix pentandra*). This vegetation, having a nearly unlimited access to water, transpires large quantities, estimated by van Hylekama to total over  $29 \times 10^9$  m<sup>3</sup>/yr.

In order to measure the actual rate of evapotranspiration, six large evapotranspirometers (surface area about 80 m<sup>2</sup>) were installed near Buckeye, Ariz., in 1959 and another five in 1962. In 1963 the salinity of the ground water in the older tanks (evapotranspirometers) had risen from an original 4,000 to over 200,000 ppm. Although saltcedar is reported to tolerate and thrive on soil moisture of high salinity the tanks were flushed out until the salinity of the effluent was back to the original. Whereas in 1963 the water use varied between 80 and 200 m<sup>3</sup> per tank per year (depending on depth to water in the tanks), after flushing, the use increased by more than 50 percent.

It is frequently assumed, when water use by phreatophytes is estimated, that the plants have access to water of low salinity. This assumption may not always be right, however, and the actual water losses may be less than estimated by as much as 40 percent.

Mapping of flood-plain areas according to the areal density of riparian vegetation was accomplished by T. W. Anderson using aerial photographs of the Agua Fria River and Humbug Creek. Preliminary data indicate that any increase in evapotranspiration losses in response to a possible increase in surface flow will be small in relation to existing losses.

#### Evapotranspiration in closed basins

C. T. Snyder investigated relict lake-shore features in Ruby Valley, Nev., and obtained information about climatic conditions that existed when Pleistocene Lake Franklin occupied the valley and precipitation exceeded evaporation. Ruby Valley is an exceptional area in Nevada in that precipitation and inflow within the drainage basin exceed evaporation, allowing 12,000 acres of marshland and 725 acres of small lakes to exist in addition to 2,300 acres of wet mud flats. The information obtained by Snyder on past and modern climates should promote more effective land management and land use in closed basins in arid areas.

#### Evaporation from lakes and reservoirs

The evaporation rate from Vail Reservoir, Riverside County, Calif., was computed, by M. W. Busby by the mass-transfer method and by the pan method, for comparison. Three variations of the empirical mass-

transfer equation were used and evaluated, with the following being the best:

$$E = 0.00473u^{0.75} (e_o - e_a),$$

where

$E$  = daily evaporation, in inches,

0.00473 = mass-transfer coefficient (best value determined empirically),

$u$  = average daily wind speed, in miles per hour, at some height above water surface, in meters, as indicated by a subscript,

$e_o$  = saturation vapor pressure, in millibars, at the water surface, and

$e_a$  = vapor pressure of the air, in millibars; height above the water surface, in meters, is indicated by a subscript.

The monthly evaporation, when estimated using either a 24-inch sunken pan or a class A pan, can be computed more accurately by using the following relation:

For the 24-inch pan:

$$\text{Evap} = Ep (0.547 - 0.0704 Ep + 0.0194 T_L - 0.0000168 St + 0.000467 S),$$

where

Evap = monthly evaporation, in inches,

$Ep$  = monthly 24-inch pan evaporation, in inches,

$T_L$  = monthly mean lake water temperature, in °C,

$St$  = month-end storage, in acre-feet, and

$S$  = mean daily solar radiation for month, in langley.

For the class A pan:

$$\text{Evap} = E_A (0.339 - 0.0880 E_A + 0.0317 T_L - 0.0000159 St + 0.000561 S),$$

where

$E_A$  = monthly class A pan evaporation, in inches and all other terms are the same.

Energy-budget and mass-transfer techniques, as developed from work at Lake Hefner, Okla., and Lake Mead, Ariz.-Nev., were used by J. S. Meyers in 1969 for estimating evaporation from Elevenmile Canyon (elevation 8,600 feet) and Dillon (elevation 9,000 feet) reservoirs in central Colorado; from Amistad Reservoir (elevation 1,200 feet) in southwest Texas; and from San Carlos Reservoir (elevation 2,500 feet) in southeast Arizona. The objective was to get better determinations of evaporation than can be obtained from evaporation pans.

Relationships are better defined for warmer and

dryer southern sites at moderate elevations than for higher, cooler, and more humid locations. Problems in calibration and interpretation of readings from radiation instruments need further development work.

A technique for separating evaporation and seepage from lakes in which seepage varies seasonally was devised by M. E. Moss. The technique combines the modified mass-transfer concept of Harbeck with Fourier analysis, and evaluates the resulting parameters by linear multiple regression. The technique was tested on four geographically diverse sets of evaporation data. Standard errors of estimates were reduced relative to the best previous analysis for three of the four data sets; while the analysis of the fourth set yielded the same standard error of estimate as the best previous analysis.

#### **Evaporation reduction by floating cover of polyethylene foam**

The results of experiments to reduce evaporation losses by floating covers of polyethylene foam (density 2.2 lb per cu ft) from small stock ponds near Laredo, Tex., during 1969 indicated the foam has the needed buoyancy to prevent the collection of water on its surface from wave action and precipitation. However, degradation of the foam by ultraviolet radiation is a serious problem. G. E. Koberg has observed that the natural foam with a thickness of  $\frac{1}{8}$  inch will have a useful life of 6 months.

To extend the life of the foam, experiments were tried using protective coverings of white and black polyethylene films. The test of the white film (4 mils) indicated it would extend the life of the foam an additional 6 months. The test of the black film (4 mils) showed that it was unsatisfactory as a protective covering because the foam collapsed to one-fourth its original thickness. The collapse of the foam is attributed to the black film raising the temperature above the safe limit for polyethylene foam.

As for the foam's ability to retard evaporation, transmission rates of water vapor through the foam are negligible when compared with evaporation from an open water surface. In the experiments at Laredo, maximum coverage of the water surface was 50 percent. Measurements of temperature in the uncovered portion of the water surface showed no increase when compared with an adjacent pond without a cover. Thus, a floating cover should reduce evaporation approximately equal to the percentage of water surface covered.

Before any practical application can be made of floating covers of polyethylene foam, problems of

anchoring and suitable protective covering must be resolved.

## **LIMNOLOGY**

### **Structure and inferred circulation of South Cascade Lake, Wash.**

In an effort to demonstrate the dynamic interplay between South Cascade Glacier, Wash., and its terminal lake, a series of limnological measurements was begun by W. J. Campbell in 1966. Summer and winter profiles of water temperature, dissolved-oxygen concentration, and specific conductance throughout the lake were defined. Summer profiles of suspended sediment were determined, and the thermal structure of the epilimnion was studied in detail using thermister and thermocouple probes and infrared radiometers. It was found that in the summer the generation of an intensive shallow epilimnion with a sharp thermocline results from the absorption of solar radiation by the highly turbid water. When this epilimnion persists throughout the summer, the circulatory mode of the lake is dimictic; when it is transitory, the mode is polymictic. In winter, double inverse thermoclines were formed, with the oxygen-rich glacial melt water flowing along the epilimnion at the ice bottom and out of the lake while the zone between the thermoclines (10 to 30 m) is a region of slow return flow toward the glacier terminus and (or) slow-moving convective cells. Apparently, little motion occurs in the winter hypolimnion below 30 m depth.

### **Eutrophication in Oneida Lake, N.Y.**

Oneida Lake is located just northeast of Syracuse, N.Y. On the basis of past descriptions, an annual nuisance of algal blooms apparently has occurred in the lake since the early 1600's. From a recent study, P. E. Greeson (r0375) reported that an abundant supply of soluble minerals and dissolved organic materials from the lake's drainage basin and continuous mixing of the nutrient-rich bottom sediments account for the development of these algal growths.

Oneida Lake is shallow with an average depth of 22.3 feet. It has a long axis lying in a nearly east-west direction. As a consequence the lake undergoes continuous mixing by the prevailing westerly and northwesterly winds which can create waves in excess of 6 feet in height that can effectively mix to a depth of about 30 feet. This wave action affects 65 percent of the lake bottom, thus subjecting nutrient-rich sediments to the mixing action of the overlying water. Drainage into the lake is from a fertile basin which was once the bottom of an inland fresh-water sea.

*Anabaena flow-aquae*, *Anabaena circinalis*, *Aphanizomenon holsaticum*, and *Microcystis aeruginosa*, all blue-green algae, dominate the annual algal blooms.

#### Water balance of Lake Kerr, Fla.

Lake Kerr, Fla., located in an area having no well-defined channels for surface drainage in north-central Florida, receives its water from precipitation falling directly upon the surface of the lake and from drainage from within the lake basin. Yearly rainfall averages 54 inches; U.S. Weather Bureau maps show that yearly lake evaporation averages 46 inches. Fluctuation of the lake level is not great for the location, occurring within a range of 7 feet during a 33-year period including unusually wet and dry intervals. In a recent study of lake-level fluctuations, G. H. Hughes found that a simple water-balance model successfully simulated monthly variation in the lake level about 70 percent of the time. The model includes only three factors; monthly rainfall on the lake, monthly lake evaporation, and an estimate of 0.1 foot per month leakage through the lake bottom. Rainfall estimates are based on rainfall recorded at two stations 20 to 25 miles from the lake; monthly evaporation estimates are based on pan evaporation, the pan coefficient predetermined by the estimate of 46 inches average yearly evaporation. Consistent success with use of the model for months of low rainfall in wet as well as dry years suggests that the effect of ground water on the lake is negligible. The model was not successful for monthly rainfalls greater than 6 inches, when variability of rainfall can increase the errors in rainfall estimates; however, the data indicate that overland runoff probably occurred and was a factor during these periods. The water-quality parameters are compatible for surface and ground water in the study area.

#### Chemical changes in Great Salt Lake, Utah

The unrestricted circulation of brine in Great Salt Lake was impaired with the construction of a permeable rockfill causeway across the lake in the late 1950's. Studies of the chemistry of the lake as controlled by the interchange of dissolved-solids load through the causeway, and by volume changes, have continued.

When the lake was divided, changes occurred in the lake hydrology which caused the two interconnected sections to have different water surface elevations and densities, and thus a resultant two-directional flow through the causeway. The net movement of load through the causeway is dependent upon the relationship between the ratio of flows in each direction and

the concentration of dissolved solids in these flows. R. J. Madison estimated that during the 1969 water year the ratio of flows was about 11 northward to one southward through the culverts in the causeway and about two northward to one southward through the fill material, with an estimated total movement of dissolved-solids load through the causeway of about 210 million tons northward for the year.

#### Effects of air injection on Lake Cachuma, Calif.

The study to determine the effects of air injection on Lake Cachuma, Calif., was continued by M. W. Busby, who reported that physical, chemical, and biological characteristics of the lake in 1969 were very similar to those of the lake in 1967. There was no apparent carryover of effects from the destratification of the lake by use of air injection in 1968.

#### Phytoplankton in a small glacial lake

Variations in the concentration of major planktonic algae in Pretty Lake, Lagrange County, Ind., through two annual cycles have been determined by R. G. Lipscomb. It has been found that beginning in mid-October the diatoms (Bacillariophyceae) predominate, with concentrations of *Asterionella formosa* from the water surface down to a depth of 10 m and *Fragilaria crotonensis* which increases in concentration with increasing depth below 10 m. Autumnal circulation about mid-November tends to distribute the algal population uniformly throughout the lake. *F. crotonensis* is the dominant species during the "overturn," but shortly after the lake is ice covered this species is replaced by a brief occurrence of *A. formosa*, mostly at a depth of about 6 m. *Cyclotella bodanica* then emerges and becomes the most concentrated form at a greater depth between 6 and 13 m beneath the ice. Its concentration increases slightly near the end of spring circulation (immediately after ice breakup) and then declines appreciably during the early summer. For nearly a 3-week period beginning in mid-May *Gomphospaeria lacustris* (Myxophyceae) is the species which occupies most of the space in the upper 4 m of water in the lake, while deeper at 8 to 10 m it is *Aphanizomenon holsaticum* (Myxophyceae). Near the end of July, *Ceratium hirundinella* (Dinophyceae) has become the most common form at the 6-m depth and is coincident with the peaking concentration of *A. holsaticum* below. By the end of September the concentration of *A. holsaticum* is significantly reduced and the diatoms are again dominant with *C. bodanica*, *A. formosa*, and *F. crotonensis* being present in about equal numbers.

## PLANT ECOLOGY

### Plant distribution at Great Falls Park, Md.-Va., related to geology and hydrology

R. S. Sigafoos found that the distributions of certain tree, shrub, moss, and lichen species were closely correlated with differences in topography at Great Falls Park, Md.-Va. Post oak grows only on bedrock terraces, red maple and pin oak only in swamps, sycamore, cottonwood, and silver maple only on fine alluvium on flood plains, and several oaks and other trees grow on well-drained uplands. A moss species grows only on cliffs that are flooded about once every 2 years. One lichen species grows only on rocky surfaces flooded several times a year, whereas other lichen species grow on rocks that are infrequently or never flooded.

### Vegetation related to flood frequency

The distribution and percentages of various tree species of the deciduous forest of the flood plain of the lower White River in Arkansas were found by M. S. Bedinger to be related to frequency of flooding. Tree species were counted in plots where frequency of flooding ranged from annual to greater than 100 years. In the parts of the valley flooded annually, the vegetative type seems to be related to duration of flooding.

### Vegetation of Amchitka Island classified

The vegetation at the supplemental atomic test site, Amchitka Island, Alaska, was classified by H. T. Shacklette (r0433) and others into 37 plant communities in 14 different types of habitat. An inventory of plant species revealed 198 vascular plants, 153 bryophytes, 84 lichens, 25 fungi, and 173 algae, for a total of 633 species of plants on the island. Five new species and one new variety of algae were found, and the known distribution range of many other species was extended. This is the only inventory of all plant species that has been made for any of the Aleutian Islands.

### Moraine ages show consistent pattern of alpine glacier recession

The eight glaciers studied by R. S. Sigafoos and E. L. Hendricks<sup>83</sup> in their research on vegetation and hydrology at Mount Rainier, Wash., started to recede between A.D. 1830 and 1850. These major glaciers were considerably farther downvalley 125 to 130 years ago than today. For three of them this stand represented the farthest advance in the last 10,000

years. The others were larger and more extended earlier, but within the last 750 years. These older moraines do not show the close correlation of recession that the youngest ones show, but this may be the result of insufficient data or may indicate different recessional patterns. In spite of the vagaries of Mount Rainier glaciers, their dynamic nature is clear.

### Relationship between atmospheric carbon dioxide and photosynthesis of saltcedar

No carbon dioxide deficiency was found by T. E. A. van Hylckama<sup>84</sup> to occur in or over a stand of saltcedar even during periods of high rates of photosynthesis. Further analysis of the data showed, however, that there is a close correlation between the carbon dioxide and water-vapor fluxes above the saltcedar thickets. A reduction in fluxes during hot afternoons appears to accompany temperatures over 40°C. Water use is similarly affected.

### Wind profiles above and within saltcedar thickets

In a study of wind profiles above a 3-m-high stand of saltcedar, T. E. A. van Hylckama<sup>85</sup> found that an analysis of hourly windspeeds showed that 90 percent of all observations of the profiles can be represented by a simple logarithmic equation:  $u_z = u^*/k \ln(z/z_0)$ , where  $u$  is the velocity at height  $z$ . The roughness length ( $z_0$ ) varies with a stability ratio (similar to Richardson's number), and the friction velocity ( $u^*$ ) with the profile slope. Von Karman's constant is 0.41. Within the thicket, turbulence is very high during daylight hours and irregular wind inversion occurs frequently.

### Estimation of hydrologic conditions from tree growth

In studying relationships near Delaware, Ohio, between current tree growth and hydrologic conditions in order to improve estimates of past hydrologic conditions from tree rings, L. C. Styer showed that negative water pressure of American elm (*Ulmus americana* L.) exhibits a diurnal fluctuation similar to radius change of the trunk. Change in radius lagged approximately 2 hours behind the negative pressure, but varied with soil water availability and weather conditions. Despite the lag effects, it appears probable that diurnal fluctuations in radius indicated by dendrograph records may be used to indicate change in negative water pressure.

Newer methods of comparing tree-ring widths with environmental parameters suggest that certain hydro-

<sup>83</sup> Sigafoos, R. S., and Hendricks, E. L., 1971, Recent activity of Mount Rainier glaciers: U.S. Geol. Survey Prof. Paper 387—B. [In press]

<sup>84</sup> van Hylckama, T. E. A., 1969, Photosynthesis and water use by saltcedar: Internat. Assoc. Sci. Hydrology Bull., v. 14, no. 1, p. 71-83.

<sup>85</sup> van Hylckama, T. E. A., 1970, Winds over saltcedar: Agr. Meteorology, v. 6, no. 3, p. 217-233.



logic information may be estimated from tree rings in an area where previous work failed to indicate any correlation. In a reanalysis of tree-ring material collected in Shackham Brook watershed in New York, R. L. Phipps found significant correlations between tree rings of extreme size and certain hydrologic parameters. High correlations existed only between certain hydrologic parameters and specific species and site combinations. Of the four species and the various combinations of site types, growth parameters, and environmental variables tested, the highest correlation existed between growth-season runoff and ring width of red pine (*Pinus resinosa* Ait.) growing on west-facing slopes such that the 3 years of greatest runoff always corresponded to the 3 years of smallest tree rings.

#### **Hydrologic effects of plant distribution and growth activities**

Studies of spring season plant phenology conducted by C. P. Baker were made in an attempt to correlate the progression of tree leafing throughout the Potomac River Basin with seasonal changes in hydrologic phenomena. As expected, a general inverse correlation was observed between time of leafing and altitude, with the result that forests of the mountainous headwaters of the basin do not begin removing water from the soil until much later than the lower portion of the basin—a factor which undoubtedly affects runoff from spring rains. No latitudinal difference in timing of leafing was observed in the basin, but a pronounced longitudinal gradient existed such that at a given altitude leafing began earlier in the western portions of the basin.

Results of preliminary work by C. S. Stone to correlate distribution of vegetation type in the Little River area, West of Harrisonburg, Va., with streamflow suggest that, independent of geology and topography, the greater the proportional distribution of yellow pine forest type, the greater the streamflow during late summer and early fall.

## **NEW HYDROLOGIC INSTRUMENTS AND TECHNIQUES**

### **MISCELLANEOUS INSTRUMENTS AND TECHNIQUES**

A real and continuing need exists in water-resources investigations for the improvement of present instruments and the introduction of more advanced and versatile equipment. Recent advances, particularly in

electronic solid-state circuitry, make it possible to conduct more accurate tests and measurements with lightweight portable equipment. New techniques are being introduced as more accurate and versatile equipment is being made available.

W. S. Keys reported that recent experiments proved the feasibility of detecting changes in the porosity and permeability of an aquifer caused by the development of a well. In the vicinity of Anchorage, Alaska, successive neutron logs were used to detect the depth and relative magnitude of development achieved by surging. Near Lubbock, Tex., gamma-gamma transmittance logs were used to detect the depth, lateral extent, and magnitude of plugging in the Ogallala Formation caused by artificial recharge through a well. Recent tests have also proven that it is possible to make multielectrode resistivity logs through a plastic well screen. This will provide another technique for investigating aquifer changes due to development and operation in the immediate vicinity of the well.

J. E. Eddy is presently working with small power supplies and amplifiers that will go down into the well casing along with various sensors. On one control unit in an underwater television system, the weight was reduced by 40 pounds by replacing tubes and transistors with new and efficient integrated circuits. This method will eliminate some of the noise and drift problems encountered from low signal sources.

J. V. Skinner and J. P. Beverage reported on the development in Minnesota of a new PS-69 pumping sampler equipped with a proportional discharge control unit. Development work on a deep-water depth-integrating sampler was initiated, and a new laboratory method for rapid determination of sediment concentration is being tested.

I. L. Burmeister reported that measuring and sampling of the Missouri River is being conducted at Nebraska City, Nebr., from a railroad bridge, using a truck provided with Hy-Rail equipment to allow the truck to operate on standard-gage rails. A rig, designed by Burmeister, was mounted inside the truck for the stream-gaging and sediment sampling operations. The truck can be driven on both highways and rails and thus can be used to make measurements from either highway or railway bridges.

L. L. Hubbard reported that data collected with the acoustic-velocity measuring system were used to compute the 1969 flow records for the Columbia River at The Dalles, Oreg. The system employs the principle that the difference in time of travel between a sound signal traveling against the stream current and a signal traveling with the stream current is a measure of

stream velocity along the line between two sound transducers.

J. H. Nakao reported that a servomanometer was modified from a bubble, gas-purged system to operate on direct water pressure in the flowing observation well at Island Beach No. 3, New Jersey. The manometer is connected to the capped well casing by flexible tubing, and a Fischer and Porter digital recorder is used with the servomanometer. Certain modifications made to the standard manometer allowed the use of a standard "bubble gage" to give satisfactory results on a flowing well affected by tides and a pounding surf. Several other methods had failed, including a barometric-type recorder. This well in addition to reflecting the changing tide, is also affected by a secondary harmonic-type fluctuation of up to 0.10 to 0.12 foot every few seconds. This modification had previously been adapted to record changes in reservoir elevation, but so far as known this is the first instrumentation of this type adapted to a flowing well.

Measuring low flow velocities of water using a hot film anemometer has been successful in both the field and laboratory. The sensing unit, a hot film anemometer, is approximately linear, indicates flow direction, and has a built-in calibration facility.

The output from temperature sensing units can now be amplified to a volt or more when used with button batteries and the small operational amplifiers now available. Strain gage sensors, previously unable to produce a signal other than in microvolts, can be used with the same type of amplifiers.

J. P. Bennett and R. S. McQuivey (p. B254-B262) have used the hot film anemometer in measuring turbulence in movable-boundary open-channel flows.

### COMPUTER TECHNOLOGY IN WATER-RESOURCES STUDIES

The application of numerical techniques to water-resources problems generally falls into three categories: (1) numerical integration of analytical solutions to the equations of motion, (2) finite-difference solutions for the equations of transport and motion, and (3) analyses of large-scale water-resources systems, often involving simulation methods.

#### Numerical integration

The unsteady flow of ground water is described by elliptic and parabolic partial differential equations. The classic method of analysis is to solve the equations for the appropriate initial and boundary conditions. It is not uncommon for the solution to take the form of an integral which is difficult, if not impossible to integrate, except by numerical methods.

M. S. Bedinger and J. E. Reed have devised a digital method for computing the response of stream-induced water-level fluctuations in an aquifer system. G. F. Pinder, J. D. Bredehoeft, and H. H. Cooper, Jr., used a method based upon the numerical convolution of a one-dimensional nonsteady equation to compute the response of a stream-aquifer system to arbitrary changes in stage in the stream.

#### Finite-difference methods

Using finite-difference techniques it is 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.

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. A computer-animated movie which shows actual particle motions during transient flow was completed by Lai.

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 California, Colorado, Kansas, New Jersey, New Mexico, and Washington. 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 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.

#### **Simulation studies**

Several simulation studies have also been undertaken in which the emphasis is on the response of a total water-resources system to water-management decisions. The U.S. Geological Survey has established a systems analysis unit, headed by N. C. Matalas, which is responsible for applying the techniques of operations research to problems of water management. Often these studies lead to the simulation of a water-resources system.

I. C. James II has completed work on a computer simulation of the conjunctive ground- and surface-water system along the Arkansas River in Colorado. This study was designed to simulate hydrologic changes in the system caused by various water-management decisions.

In cooperation with Resources for the Future, Inc. (a nonprofit corporation for research and education in the development, conservation, and use of natural resources), research was done in which economic-decision models have been linked with hydrologic models in order to formulate an overall water-resources model of a hydrologic system. J. D. Bredehoeft, working with R. A. Young (Resources for the Future), has developed a computer simulation which can be used for the hydrologic and economic analysis of a purely ground-water system. A second simulation model was developed for a conjunctive ground- and surface-water system. Both these models have been used to study the economic effects of various management decisions.

## **SEA-ICE STUDIES**

### **The National Data Buoy Systems approach to Arctic Ocean studies**

The rheological properties of the sea-ice canopy covering the Arctic Ocean are only partially known. Its fracturing appears to play a major role in the heat balance of the ocean, and its ability to transmit large horizontal stresses profoundly affects the dynamics of the ocean. Studies of ocean and sea ice have been made by using single drifting stations of manned ice floes, ice islands, and embedded ships, but

this has been expensive and has yielded fragmented, nonsynoptic data which fail to completely explain the complex dynamic interplay. The needed data according to W. J. Campbell can be obtained only by a grid of multiple drifting stations equipped to measure (1) the wind stress at the ice-air interface, (2) the water stress of the ice-water interface, (3) the current structure of the ocean, and (4) the absolute position of each buoy. The rheological properties of the canopy must be studied by measuring sea-ice deformation at time scales of the order of hours and space scales of the order of 100 km, such that individual floes do not constitute a significant portion of the deformation area. This could be done by equipping each buoy with a geodetic satellite receiver and thus obtaining the strain between buoys. Numerical studies have had some success by treating the canopy as a highly viscous fluid, but recent work indicates that it is probably more like a viscoplastic solid. The National Data Buoy System appears to be the feasible way of determining the characteristics of the Arctic Ocean and its ice cover.

### **Investigations of sea-ice movements**

Early work on sea-ice drift visualized the ice moving under the action of three forces: air stress (wind), water stress (drag), and Coriolis force. Subsequent work sought to overcome the inadequacies in the three-force model by incorporating a logarithmic boundary layer at the ice-water interface. This concept gave a much better agreement between observed and theoretical wind-ice velocity correlations; however, when the data from manned ice floes, ice islands, and ships embedded in the ice canopy became more accurate and detailed, it was more apparent that basic changes in the three-force model were needed.

Inadequacies of still more complex models caused W. J. Campbell to construct a model in which the ice moved under the influence of five forces: air stress, wind stress, Coriolis force, gradient currents, and internal ice stress. Furthermore, it allowed for the boundary layer at the ice-water interface. Campbell solved the model for the case of the mean annual flow of the Arctic Ocean. The solution showed the Beaufort Sea gyral with the correct size and position and gave the correct solution for the mean annual ice flow. However, this model gave an unrealistically great ice convergence in the Beaufort Sea gyral. This occurred because in a Newtonian fluid the resistance to compression is the same as that for tension. In reality the strength of large sheets of neutral sea ice must be represented by an exceedingly complex function. The strength is probably near zero for pure extension and

considerable for compression. The resistance to shear is probably near that for compression since leads are jagged. Campbell and L. A. Rasmussen are working on a model in which the internal ice stress is treated as a double Newtonian fluid, such that when a compressive mode exists the ice is highly viscous and for an extensive mode a low viscosity exists. The model must be tested with detailed observations of ice deformation because such anisotropies of the internal ice stress are impossible to deduce from existing data. Thus it is necessary to study the rheological properties of sea ice for mesoscales and macroscales.

## **ANALYTICAL METHODS**

### **ANALYTICAL CHEMISTRY**

#### **Rapid scanning technique for carbon dioxide in rocks**

A rapid scanning technique for determining carbon dioxide concentrations ranging from 0.00 to 0.10 percent in rocks was developed by Leonard Shapiro. Carbon dioxide evolved by acid from a 25-mg sample is collected in a small sidearm attached to a test tube and the volume compared to that generated from a standard. Samples can be analyzed at the rate of a few minutes per sample. The procedure is particularly useful for screening samples containing more than 0.1 percent  $\text{CO}_2$  when more accurate methods are warranted.

#### **Gas chromatographic method for carbonate carbon in rocks**

A simple, rapid, and direct gas chromatographic method for determining carbonate carbon in rocks and minerals was developed by J. W. Marinenko and Irving May. Powdered samples are heated with phosphoric acid, and evolved gases are separated on a silica gel column. Carbon dioxide is detected by thermal conductivity using helium as a carrier gas. The method is most suitable for applications when a limited quantity of sample prohibits the determination of carbon dioxide by conventional methods at minor and major concentration levels. As little as 2  $\mu\text{g}$   $\text{CO}_2$  can be determined with a relative error of about 10 percent. For major concentrations of carbon dioxide, a coefficient of variation of 1 to 2 percent is obtained.

#### **Fluoride-specific electrodes applied to determining fluoride in rocks**

B. L. Ingram and Irving May applied the fluoride-specific electrode to procedures for determining fluoride in phosphate and silicate rocks. The use of sodium citrate reduces interference of aluminum, enabling determinations to be made in most cases without the

necessity of isolating fluoride by distillation. The combination of aluminum and fluorine in phosphate rocks allows the determination to be made directly after addition of citrate to a suitably diluted acid leach of the sample. Silicate rocks containing 0.004 to 0.20 percent F, and less than 19 percent  $\text{Al}_2\text{O}_3$ , can be analyzed with the electrode technique which gives results within 5 percent of the true values. Samples are fused with sodium carbonate-zinc oxide, leached, filtered, and acidified with hydrochloric acid. An aliquot of the sample solution is adjusted to 0.1M sodium citrate and 0.1M potassium nitrate. The potential is read with a fluoride-sensitive electrode in conjunction with a saturated calomel reference electrode. The citrate eliminates aluminum interferences, but it causes sluggish electrode response at fluoride concentrations less than 1 ppm. To overcome this problem a technique was developed using two fluoride electrodes. One electrode is used both for preliminary rapid reading of solutions to establish the range and also for determinations in solutions above 0.15 ppm. The second electrode is used only for solutions containing less than 0.15 ppm. To further control errors due to slow response, each sample and standard is read immediately after a 0.15-ppm standard for the low range and a 1-ppm standard for the high range. Good results are obtained when 10 minutes is allowed for electrode equilibration. Response is sufficiently rapid above 1 ppm that special potential measurement techniques are not required.

#### **Study of analytical methods for barium and strontium**

Barium and strontium in silicate rock and mineral reference samples have been determined by a variety of methods including isotope-dilution mass spectrometry, emission spectrography and spectrometry, flame-emission and absorption spectrometry, X-ray fluorescence spectrography, and classical methods. This study in analytical methods development was used by C. O. Ingamells and B. P. Fabbi in collaboration with N. H. Suhr and F. S. Tam (Pennsylvania State University) to detect interferences and errors. Highly reliable values for barium and strontium in several reference samples were obtained.

#### **Determination of small amounts of arsenic**

M. M. Schnepfe and Irving May modified and improved the procedure of Vařák and Šedívek for determining arsenic.<sup>86</sup> Arsenic is evolved as arsine by adding zinc shot to a solution of the sample containing hydrochloric and sulfuric acids and stannous

<sup>86</sup> Vařák, Vladimír, and Šedívek, Václav, 1952, Colorimetric determination of arsenic: *Chem. Listy*, v. 46, p. 341-344.

chloride. The arsine gas is passed into a pyridine solution of silver diethyldithiocarbamate to yield a red complex whose absorbance is determined at 540  $m\mu$ . Approximately 0.02 ppm As is determinable in the pyridine solution. Modifications which include the elimination of potassium iodide and which increase the concentration of other reagents permit arsenic to be determined in the presence of relatively large amounts of antimony and copper which would otherwise interfere. The simplicity of both the procedure and the self-contained apparatus suggest ready application to geochemical exploration studies.

#### Determination of cobalt by atomic absorption

Wayne Mountjoy completed the development of an atomic absorption method for determining cobalt in geologic materials (p. B174-B176). Approximately 2 ppm Co can be determined as a lower limit on a sample. A dilute hydrochloric acid solution obtained after the decomposition of a 1-gram sample is adjusted to pH 3 to 4 in the presence of sodium citrate. A solution of 2-nitroso-1-naphthol is added and after one-half hour the cobalt complex is extracted into methyl isobutyl ketone. Cobalt in the organic phase is then determined by atomic absorption spectroscopy. Results obtained with this method on seven U.S. Geological Survey reference samples are in good agreement with the accepted values for cobalt.

#### Atomic absorption methods for ore prospecting

Detailed atomic absorption methods of analysis for geochemical prospecting for ore deposits were developed by F. N. Ward, H. M. Nakagawa, T. F. Harms, and G. H. Van Sickle (r0250). Procedures given include determination of Ag, Bi, Cd, Cu, Pb, Zn, Co, Ni, Ca, Li, Na, K, Au, Te, and Hg.

#### Atomic absorption determination of iridium

F. S. Grimaldi and M. M. Schnepfe<sup>87</sup> developed a new procedure for the concentration and atomic absorption determination of iridium in mafic rocks. Iridium, together with palladium, platinum, and rhodium, is collected into a gold bead after fire-assay fusion and cupellation. Recovery of all four platinum metals is quantitative with slag compositions varying from orthosilicate to metasilicate. Interelement interferences in the atomic absorption determination are removed and iridium sensitivity is increased by buffering the solutions with a mixture of copper and sodium sulfates. Substantial amounts of Ag, Al, Au, Bi, Ca,

Cd, Co, Cr, Fe, Ho, Hg, K, La, Mg, Mn, Mo, Ni, Pb, Te, Ti, V, Y, Zn, and the platinum metals can be tolerated. The sensitivity and detection limits in solution are 3.2 and 0.25 ppm Ir, respectively. A few ppm of iridium can be determined on a 20-g sample. Platinum, palladium, and rhodium can be determined simultaneously on aliquots of the sample solution.

### X-RAY FLUORESCENCE

#### Oxidation states of manganese as revealed by soft X-ray spectrometer

Study of the X-ray emission L spectra of manganese in different compounds by J. R. Lindsay and H. J. Rose, Jr., revealed that the intensity ratio of  $L_{\alpha 1,2}/L\beta$  depends primarily on the oxidation state of manganese, but no correlation was found between the oxidation states and the wavelength shifts of  $L\alpha$  and  $L\beta$ . Their data for several manganese valences are:

	Intensity $L_{\alpha 1,2}/L\beta$
Mn -----	5.37
MnO <sub>2</sub> -----	2.14
Mn <sub>2</sub> O <sub>3</sub> -----	1.80
Mn <sub>3</sub> O <sub>4</sub> -----	1.65
MnO -----	1.30
MnCO <sub>3</sub> -----	1.29

#### X-ray fluorescence analysis of rocks

B. P. Fabbri developed an X-ray fluorescence procedure for analyzing rocks and minerals. Rocks are fused with a 7 to 1 ratio of LiBO<sub>2</sub> to sample, ground to 20 $\mu$ , and pressed into a pellet. The intensity ratios of phosphorus, iron, aluminum, and silicon are corrected for matrix or interelement effects. Magnesium, calcium, potassium, titanium, manganese, and sulfur are not corrected. The average relative error is 2.5 percent of the amount present over a concentration range of 0.01 to 75.0 percent of the oxide. This technique is reasonably accurate and is useful for many routine rock analyses. For some minerals, however, a greater sample dilution is necessary to achieve this accuracy.

### ACTIVATION ANALYSIS

#### Background-level determinations of osmium, ruthenium, and iridium in rocks

The determination of osmium, ruthenium, and iridium at background levels in geologic samples is a formidable problem. R. H. Gijbels (exchange visitor, University of Ghent, Belgium) in collaboration with H. T. Millard, Jr., and G. A. Desborough developed an activation analysis procedure for these elements. One-gram samples are irradiated for 80 hours in a neutron flux of  $2 \times 10^{13}$  n/cm<sup>2</sup>/sec. Radiochemical separations, designed to yield osmium,

<sup>87</sup> Grimaldi, F. S., and Schnepfe, M. M., 1970, Determination of iridium in mafic rocks by atomic absorption: *Talanta*, v. 17. [In press].

ruthenium, and iridium fractions which are radiochemically very pure, are used to allow low-level counting. These separations are long and tedious, and only three samples can be processed per week. Each of the three elements is counted on a Ge(Li) detector. The nuclides measured are 15-day  $\text{Os}^{191}$ , 40-day  $\text{Ru}^{103}$ , and 74-day  $\text{Ir}^{192}$ . It is necessary to determine the uranium in each sample by a fission-track method to correct for  $\text{Ru}^{103}$  produced by fission of the uranium. The detection limits of the technique with a coefficient of variation of 10 percent is 0.5 ppb Os, 1 ppb Ru, and 0.01 ppb Ir. This procedure was used to determine these elements in 17 samples from the Bushveld Complex.

#### **Triple coincidence counting of iridium in chromites**

L. P. Greenland, J. I. Dinnin, and J. J. Rowe applied triple coincidence counting after neutron activation for the instrumental determination of iridium in chromites. The 74-day  $\text{Ir}^{192}$  decays, among other modes, through a triple-gamma cascade with energies of 0.316, 0.308 and 0.296 Mev. The coincidence counting system consists of two 3 inch x 3 inch and one 4 inch x 4 inch NaI crystals coupled to three single-channel analyzers. Two of the analyzers have their windows set to include the 0.28 to 0.34 Mev range, while the third includes the 0.20 to 0.45 Mev range. All coincidence pulses are recorded on a scaler, and these pulses also gate a multichannel analyzer which records the signal going through the third analyzer system. Reasonably reliable determinations of iridium in chromites can be made at concentrations of 10 ppb or greater, as shown by comparison with samples which were processed through the radiochemical separations of the iridium.

#### **Instrumental neutron activation analysis of geologic samples**

Several groups have reported the use of high-resolution Ge(Li) detectors for instrumental neutron activation analysis (INAA) of geologic samples. In this technique, samples are irradiated and counted without the need for radiochemical separations. While establishing an INAA system, P. J. Aruscavage and H. T. Millard, Jr., hoped to improve on the results obtained in the past by using well-calibrated monitors which approximate the composition of the samples being analyzed and by controlling the counting conditions more rigidly. Standard solutions containing the elements of interest were carefully prepared and calibrated against other independently prepared standard solutions. Synthetic rock standards were prepared by pipeting aliquot portions of the solutions

of the elements onto quartz powder, drying the powder, grinding to 100 mesh, sieving, and mixing. The homogeneity of these synthetic rock standards and standard G-2 with respect to the INAA elements was determined by irradiating and counting five 1-gram replicates of these powders. No inhomogeneity was revealed for these standards. The INAA elements may be grouped according to the precision with which they can be determined (that is, the coefficient of variation based on counting statistics) in a sample of G-2 composition as follows: 1 to 10 percent, Mn, Na, K, Hf, Ta, Sc, Fe, Ce, Th, Nd, Eu, Sm, and La; 10 to 20 percent, Dy, Ba, and Yb; 20 to 50 percent, Lu, Cs, Cr, and Zr. This technique was used to determine these elements in 30 volcanic ash samples.

#### **Comparator for viewing fission tracks**

J. R. Dooley, Jr., R. B. Taylor, and F. J. Jurceka designed and built a two-microscope comparator to facilitate uranium-distribution studies being carried out by the induced fission-track method. Two monocular petrographic microscopes were incorporated into a single unit so that an adjustable sample holder can be used to align a sample and a lexan overlay for simultaneous viewing. The induced fission tracks developed in lexan plastic can, therefore, be precisely correlated with corresponding uranium-bearing grains in rock samples by direct observation following simple alignment procedures. The fields of the two microscopes can be photographed with a simple photomicrographic camera on separate halves of a 4 inch x 5 inch negative for a permanent record.

#### **Spectrographic determinations of platinum metals**

Direct excitation of a fire-assay concentrate for determining the platinum metals has always been very attractive because of its simplicity. The usefulness of the method has been limited because of frequent large fluctuations in results. A successful solution to this problem was developed by A. F. Dorzopf, Jr., and F. W. Brown. Platinum, palladium, and rhodium are determined by direct spectrographic analyses of a 4-mg gold bead obtained by fire-assay fusion and cupellation. Samples from 10 to 30 g, depending on the expected levels of platinum-group metals, are fused and cupelled using gold as a collector. The resultant bead is weighed and placed into a graphite electrode containing 2 mg  $(\text{NH}_4)_2\text{OsCl}_6$  which stabilizes the platinum volatilization. The bead is made the anode of a 15 amp d-c arc in a shielded 70-percent argon-30-percent oxygen atmosphere. The spectra are recorded on Kodak III-O plates with an Ebert 3.4-m spectrograph, and the

intensity of the analysis lines determined. Detection limits for the platinum-group metals in a one-assay-ton sample are below 1 ppb for Pd and Rh and below 5 ppb for Pt. Data indicate a probable detection limit for Ru and for Ir to be 50 ppb, but the unavailability of analyzed standards prevented the establishment of positive values for the determination of these elements. Analyses in parts per billion of standards W-1 (Pt, 14.9; Pd, 15.4; Rh, < 1); PCC-1 (Pt, 10.5; Pd, 5.5; Rh, 1.0); DTS-1 (Pt, 4.2; Pd, 0.7; Rh, 0.9) agree with values reported previously.

## ANALYSIS OF WATER

### Automated determinations using the AutoAnalyzer

The use of the Technicon AutoAnalyzer for the determination of several constituents in water were studied by D. E. Erdmann. Its use has been found applicable for the routine determinations of ammonia, chloride, iron, orthophosphate, silica, and vanadium. In the interest of uniformity, the automated methods have been kept similar in principle, when possible, to manual methods. It is possible to perform up to 40 determinations per hour. The accuracy and precision are comparable to that of manual methods, and the time and labor necessary for the determinations of these substances in water is substantially reduced.

### Atomic absorption methods for barium, beryllium, and silica

Methods for determining barium, beryllium, and silica in water by atomic absorption were set up by M. J. Fishman. For barium and beryllium, the samples are aspirated directly with no pretreatment other than addition of an ionization suppressant and dilution or filtration as may be required. No pretreatment other than dilution or filtration is required for silica.

The methods require the use of a nitrous oxide-acetylene flame. As little as 0.1 mg Ba/l, 0.01 mg Be/l, and 0.5 mg SiO<sub>2</sub>/l can be detected.

### Automation of atomic absorption analyses

M. J. Fishman and D. E. Erdmann automated atomic absorption analyses by the addition of an automatic sampler, a proportioning pump, and a strip-chart recorder. Copper, lithium, manganese, potassium, sodium, iron, and zinc are determined directly with the sampler and recorder. For calcium, magnesium, and strontium, the proportioning pump adds the required amount of lanthanum chloride solution to the samples, mixes the solutions, and delivers the solutions to the aspirator. This technique results in a significant saving of time, because manual techniques

require volumetric pipeting both of the samples and of the lanthanum chloride solution.

Sampling speeds for these constituents ranged from 30 to 60 samples per hour. The proportioning pump can also be used for automatic dilution. Accuracy of these automated techniques is equivalent to that of manual techniques

### Automated potentiometric determination of chloride in water

M. J. Fishman and O. J. Feist, Jr., (p. C226-C228) applied automated potentiometric titrimetry to the determination of chloride in water. Chloride is titrated with standard silver nitrate solution, and the end point is detected potentiometrically using chloride ion-selective and reference electrodes. The titrimer is programmed to carry out consecutive titrations automatically. Comparison of results obtained by the potentiometric method with those obtained by other automated methods shows that it is as accurate and reproducible as other methods. An advantage of the method is the elimination of interference due to any color present in the sample.

### Identification of organic constituents in water

The application of the flame-photometric detector in gas chromatographic analysis of phosphorothioate pesticides was significantly improved by an effluent splitting valve developed by D. F. Goerlitz and L. M. Law. The splitter eliminates flame blowout at sample introduction, allowing use of the full capacity of the chromatographic column and reducing the extraneous emissions from the flame jet.

L. M. Law and D. F. Goerlitz developed a micro-column adsorption technique for removing extraneous material from water and soil extracts for pesticide analysis. In addition to being rapid and convenient for this purpose, it was found to be a valuable technique for separating the chlorinated hydrocarbon insecticides from many of the phosphorothioate insecticides. When alumina is used as the adsorbent, aldrin, carbophenothion, *p,p'*-DDT, dieldrin, endrin, heptachlor, heptachlor epoxide, isodrin, lindane BHC, Methyl Trithion, and VC-13 are eluted in the first fraction (8.5 ml of *n*-hexane). The insecticides dioxathion, diazinon, ethion, malathion, methyl parathion, and parathion elute in the second fraction (8.5 ml of 1:1 benzene-hexane). The microcolumns retain their "cleanup" function when used for this purpose.

In identifying organic constituents in water, M. C. Goldberg used gas chromatographic separations and computer-assisted mass spectrometric identification to



qualitatively and quantitatively characterize the organic constituents in surface and ground waters.

A computer program capable of sorting among 7,000 high-resolution mass spectrograph tracings was implemented on the Department of Interior's IBM 360 Model 65 computer. Unknown spectra can be matched to library spectra in less than one minute or a "closeness of fit" description can be obtained if the library does not contain the unknown.

M. C. Goldberg designed a continuous liquid-solvent extractor that uses organic solvents heavier than water. The extractor is capable of handling input rates up to 2 l/hr and has a 500-ml extractant capacity. Extraction efficiency is dependent upon the  $p$  value for the solvent-solute ratio. Extractors can be serially coupled to increase efficiency. An equation relating number of extractions to solute takeout efficiency was formulated; hence, any desired extraction efficiency can be calculated. Goldberg's extractor can be coupled to other types to enable extraction of the complete spectrum of organic materials in water.

#### **Measurement of organic pollution by total organic carbon**

To be effective, pollution control measurements must be rapid. Historically, organic pollution has been measured by the 5-day biochemical oxygen demand (BOD) method. Recent literature suggests that the total organic carbon (TOC) analyses could suitably replace the BOD method as a pollution monitoring method. Evaluation of literature and laboratory results show that, although the values obtained are not identical as different parameters are measured, TOC is sufficiently sensitive and reproducible for replacing the conventional BOD method.

#### **Adaptation of radon method of analysis for radium in water to rocks and sediments**

Preliminary radium analyses by radon emanation were performed on a number of U.S. Geological Survey standard rock samples. The radon method of radium analysis is routinely used for determining low levels of radium in water samples. V. J. Janzer reported that only minor modifications of the method made it suitable for rock and sediment analysis. The radium values determined for the standard rocks agreed closely with those obtained by various indirect methods such as inference from knowledge of the uranium equilibrium or by gamma spectrometry. Measurement of the radium by radon provides a direct method free of interferences.

#### **Use of TRIGA reactor in trace-elements studies**

Several hundred samples were activated in the TRIGA (Training, Research, Investigations, Gulf

Atomic) reactor, which provides nuclear support for the trace-elements projects of the U.S. Geological Survey. G. P. Kraker reported that the problem of argon-41 release from the reactor is under quantitative evaluation. Improvements in the pneumatic tube transport system, including an electronic signal to actuate a timer in the receiving laboratory were made. Outstanding problems encountered in the use of the reactor were discussed at a national meeting of personnel engaged in the projects.

#### **Determination of organic nitrogen in suspended stream sediments**

The organic nitrogen content of small, milligram samples of suspended sediment can be accurately determined by a modified micro-Kjeldahl procedure, according to R. L. Malcolm. The catalyst, acid concentration, and length of digestion are critical to the conversion of organic nitrogen to ammonia. The ammonia distillation apparatus has been modified with a distilling head and thistle-tube assembly such that no ammonia is lost within the closed system upon base addition and distillation. Results of Kjeldahl nitrogen analysis on water-sediment mixtures may be low if acid concentration is low.

#### **Biological effects on stored water samples**

Biological effects on the composition of water samples were studied by G. G. Ehrlich and K. V. Slack. In experiments conducted by Ehrlich, samples of fresh water were enriched with nitrate, phosphate, glucose, and various combinations of the three nutrients, and stored under various conditions. When stored in darkness, net decreases in soluble nitrate and phosphate occurred only when glucose was added. Uptake of nitrate and phosphate was attended by a large increase in the bacterial population. In the absence of glucose in the dark, no marked change took place in the level of bacterial population even when enriched with nitrate and phosphate.

When samples of the same water enriched with nitrate and phosphate but not glucose were exposed to sunlight there was a rapid increase in the algal population with the disappearance of nitrogen and phosphorus and a minor but significant increase in the bacterial count.

Thus, soluble inorganic nutrients can be assimilated either by bacteria in the presence of an organic energy source, or by algae in the presence of light as the energy source. Samples for water quality analysis should be treated with a suitable preservative to inhibit bacterial action. In the absence of soluble organic matter, however, preservative need not be added, but the samples should be stored in the dark.

**Water analysis by neutron activation analysis**

An analytical method for silver at concentrations of tenths of a nanogram per liter was developed by L. L. Thatcher. The silver is complexed with thiocyanate and is collected on a specially prepared anion-exchange resin. This is eluted with a few milliliters of nitric acid, and the solution is activated for 2 minutes.

The radioactivity of the silver-110 (24-second) activation product is then counted.

An exploratory pollution survey on the South Platte River in Colorado was carried out by neutron activation analysis. Industrial pollution contributed manganese, bromine, and copper. This method appears very promising.



## **GEOLOGY AND HYDROLOGY APPLIED TO ENGINEERING AND THE PUBLIC WELFARE**

### **EARTHQUAKE STUDIES**

#### **GEOPHYSICAL STUDIES**

##### **Earthquake prediction**

Earthquake prediction, long a hope of scientists in earthquake-prone countries, is advancing toward realization. L. C. Pakiser, J. P. Eaton, J. H. Healy, and C. B. Raleigh (r0486) pointed out that changes in the rates of vertical and horizontal motions and the intensity of the earth's magnetic field have been observed, in active fault zones in California and Japan, to precede the occurrence of earthquakes and fault-creep episodes. These observations suggest that short-range prediction of earthquakes (on the order of hours or days) may be achieved through continuous monitoring of ground tilt, strain, seismic activity, and magnetic-field fluctuations, accompanied by measurements of rock stress in fault zones.

Trial predictions of earthquakes have actually been attempted by Japanese scientists at Matsushiro and by American scientists on the San Andreas fault zone in central California. R. O. Burford is attempting to devise a method for predicting earthquakes based on rapid changes in the rate of fault creep—the quiet, steady-to-episodic slippage along a fault—that have been observed to occur prior to small earthquakes. Several trial predictions by Burford are considered to be qualified successes: the observed level of seismic activity on the San Andreas fault about 40 km south-east of San Juan Bautista did increase significantly within 20 to 30 km of the anticipated locations and during a predicted 1- to 2-month time interval.

##### **Earthquake control**

L. C. Pakiser, J. P. Eaton, J. H. Healy, and C. B. Raleigh (r0486) also assessed the prospects for earthquake control by injecting fluids into stressed rocks to induce harmless fault creep and (or) small to moderate earthquakes in fault zones, thus possibly eliminating the dread hazard of destructive and death-dealing earthquakes on faults such as the San Andreas. The prospects for earthquake control have been enhanced by the observation of C. B. Raleigh, J. P. Bohn, and J. H. Healy (r1498) that earthquakes in the Rangely oil field in northwestern Colorado,

located by a dense seismic network, are occurring along a preexisting fault which is active only in the part of the field where the fluid pressure is abnormally high; this suggests that they are brought on by the water that is injected around the margins of the field to increase oil recovery. An attempt will soon be made to stop the earthquakes by reducing the pressure in the earthquake zone. If the earthquakes can be stopped, an attempt will be made to start them up again by raising the pressure.

R. M. Hamilton and Healy have shown that a seismic aftershock zone at the Nevada Test Site induced by a high-yield underground nuclear explosion was markedly less active when a later explosion was detonated nearby, suggesting that much of the earthquake potential may have been “drained” from the immediate region of the earlier explosion. This suggests another approach to earthquake control.

##### **Earthquake mechanics**

Applied experiments in earthquake prediction and control depend on improving our understanding of the mechanics of earthquake generation. Such studies are continuing in California and elsewhere. The number of seismograph stations telemetering earthquake data to the National Center for Earthquake Research (NCER) in Menlo Park, Calif., has doubled during the past year. At present, 71 stations in central and eastern California and in the vicinity of the Santa Barbara channel are transmitting continuous seismic data to NCER by radio links and telephone lines. Additional networks in Colorado, Nevada, and Washington increase the total number of stations telemetering to NCER to 124.

About 3,500 earthquakes were located in central California during the 22-month period ending October 1969. Studies of these earthquakes show that (1) almost all occur in narrow vertical zones to depths of 15 km, (2) the most active region is near Hollister where the microearthquake activity seems to be transferred from the main San Andreas fault to its subsidiary branches: Sargent, Calaveras, and Hayward faults, and (3) fault-plane solutions of several hundred earthquakes indicate predominantly right-lateral strike-slip motion. Results from these studies have been recently summarized by J. P. Eaton, W. H. K.

Lee, and L. C. Pakiser<sup>88</sup> and by W. H. K. Lee, J. C. Roller, and J. P. Eaton (r0947).

The aftershocks of two earthquakes (magnitudes 5.6–5.8) that occurred near Santa Rosa, Calif., on October 1, 1969, were studied by J. D. Unger and J. P. Eaton (r2582). The aftershocks were monitored for about 20 days by a dense network of portable seismograph stations. Locations were determined for more than 100 local events. Most of the aftershocks fell along a linear trend striking N. 25° W. and centered about 3 km northeast of the center of Santa Rosa, apparently marking an extension of the Healdsburg fault which has been mapped along the same line 10 to 15 km northwest of the aftershock zone. Focal depths of the aftershocks range from the surface to 14 km, and fault-plane solutions consistently indicate right-lateral strike-slip fault motion.

Analysis of fault-creep and geodetic data for the seismically active section of the San Andreas fault between Cholame and San Juan Bautista, Calif., by J. C. Savage and R. O. Burford (r1523) indicates that fault creep with little or no elastic strain accumulation has been the primary accommodation mechanism for the past 30 years. In this segment of the San Andreas fault, elastic energy appears to be released almost continuously in the form of fault creep accompanied by small to moderate earthquakes, thus providing a “safety valve” that may inhibit the storage of much larger amounts of energy. In other areas crossed by the fault, such as the San Francisco Peninsula where the great 1906 earthquake did so much damage, the safety valve seems to be missing; few small earthquakes are recorded there, and no fault creep has been observed.

Results from an aeromagnetic reconnaissance along the San Andreas fault between San Francisco and San Bernardino were analyzed by W. F. Hanna, R. D. Brown, Jr., D. C. Ross, and Andrew Griscom. The aeromagnetic data, supplemented by ground magnetic data, define areas of abundant subsurface serpentinite and suggest that many areas characterized by fault creep and minor earthquakes are underlain by serpentinite at shallow depths. Areas characterized by little or no fault creep and major earthquakes appear to correlate with areas where subsurface serpentinite is either deeply buried or absent. Thus, water-saturated serpentinite may be the “lubricant” of the

safety valve in the active segments of the San Andreas fault zone.

Locations have been determined for about 180 of more than 1,000 microearthquakes detected by the 7-station telemetered network in the vicinity of the Hanford, Wash., facility of the U.S. Atomic Energy Commission. A. M. Pitt and Eaton report that, during a 12-month period, about one-fourth of the seismic events occurred in a 5-km-diameter area at the eastern edge of the Hanford site. Most of the others occurred along a 50-km-long northwest-trending zone immediately north and east of the site. All the events located were smaller than magnitude 2 and most had focal depths of less than 5 km.

### Ground motion

R. D. Borchardt (r2569) monitored seismic motions in the San Francisco Bay area induced by large nuclear tests at the Nevada Test Site. His analysis shows marked variations in the amplitudes of ground motion that are consistently related to the geology of the recording sites. Spectral amplification curves computed from the nuclear-test recordings show good agreement with curves computed from the U.S. Coast and Geodetic Survey's strong-motion records of the March 22, 1957, San Francisco earthquake, and variations in ground response from the nuclear tests show consistent correlations with intensities of the 1906 San Francisco earthquake. Such studies may provide a guide to possible structural damage and ground failure in future large earthquakes.

### Earthquakes and volcanoes

Portable seismograph networks were operated in the vicinity of Mt. Rainier, Wash., and Mt. Lassen, Calif., to study earthquakes associated with these volcanoes of the Cascade Range. About 65 earthquakes were located in the Mt. Rainier area: some 80 percent were in an arcuate pattern roughly concentric with the volcano at depths ranging from the surface to 15 km; 10 percent were generally beneath the summit crater at depths ranging from the surface to 20 km.

About 30 earthquakes were located in the vicinity of Mt. Lassen, in the region of Brokoff Mountain—the western rim of a caldera formed by the collapse of ancient Mt. Tehama—and in a north-northwest-trending zone passing through Lassen Peak. Magnitudes of the Lassen earthquakes ranged from −0.9 to 1.9.

The field expeditions to Mt. Rainier and Mt. Lassen were preliminary steps in evaluating the feasibility

<sup>88</sup> Eaton, J. P., Lee, W. H. K., and Pakiser, L. C., 1970, Use of microearthquakes in the study of the mechanics of earthquake generation along the San Andreas fault in central California: *Tectonophysics*, v. 9. [In press]

of establishing a volcano-warning system using satellite telemetry of earthquake and tilt data.

## GEOLOGIC STUDIES

### Patterns of historic and geologically recent fault movement

In 1967, a new series of maps was initiated, designed to show the location of the most recently active breaks along the San Andreas and other major fault systems in California. Several maps in this series were released during the past year to supplement those previously available. With the release of a map covering the San Andreas fault from Point Delgada to Bolinas Bay (R. D. Brown, Jr., and E. W. Wolfe, r1890), strip maps became available for the entire length of the main San Andreas fault system—except for the segment between San Francisco and the northern Gabilan Range.

Other new maps cover the San Jacinto fault zone between the San Bernardino area and Borrego Valley (R. V. Sharp, r0890). A third map, prepared in cooperation with the California Institute of Technology, depicts ground surface breaks formed at the time of and following the 1968 Borrego Mountain earthquake in Southern California (U.S. Geol. Survey and California Inst. Technology, r2390).

### San Andreas fault system, California

The problem of finding and evaluating methods of determining past movements on the San Andreas fault system and dating them received further attention. For example, R. E. Wallace, in continuing research into using tree-ring chronology to date relatively recent fault movements, joined with V. C. LaMarche, Jr., (University of Arizona, Laboratory of Tree-Ring Research) in evaluation of this method. Their study revealed that although only a very few trees in unique situations can provide useful dating evidence, such trees do exist. One such tree, situated on the 1906 rupture in Fort Ross National Historic Monument, was tilted and split by fault movement in 1906 and at least twice previously in its lifetime of about 500 years; once about 400 years ago and again sometime between then and 1906.

The amount of sediment in some sags along the northern part of the San Andreas fault was calculated by André Sarna (University of California, Berkeley). When compared with normal erosion rates and areas of the drainage basins from which the sediments might have been derived, the data suggest that several sags may be no more than a few thousand years old. As appreciable cumulative movement along the fault is probably required to develop such features, Sarna

and Wallace suggest that rates of deformation over the last few thousand years must be relatively high, possibly higher than long-term average rates.

Data relating to much earlier movements on the San Andreas fault were obtained by H. C. Wagner and J. A. Bartow from examination of records of approximately 400 exploratory and producing oil wells in the Carrizo Plain-Temblor Range area of south-central California. Large displacement since middle Miocene time, with initiation of displacement prior to that time, is suggested by evidence of significant folding and (or) faulting for Late Cretaceous, Paleocene, middle Eocene, late Oligocene, early, middle and late Miocene, and middle Pleistocene times, a period of time extending over 70 million years. The limited study area prohibited determination of relative amounts of movement along the fault for different time intervals. Early phases of petroleum migration and accumulation in this part of the San Joaquin basin may reflect responses to tectonic pressure and folding prior to initial and successive ruptures along the San Andreas fault.

### Recent breaks on the Garlock fault system, California

The Garlock fault reveals significant variation in preservation of evidence of latest movement at various locations along its 250-km length, according to M. M. Clark (r0931). At its western end the youngest trace of the Garlock fault is distinctly older than the intersected most recent (1857) trace of the San Andreas fault. In general, scarps, ridges, valleys and offset drainages become progressively better preserved and hence apparently younger to the east, although decreasing rainfall eastward also strongly influences preservation.

Freshest evidence of displacement occurs in an area west of Pilot Knob Valley and in another area east of Leach Lake, near the eastern end of the Garlock fault system. In these two areas low scarps traverse nearly all terrain except the active parts of stream channels; many small offset ridges, gullies, and flow lobes of debris imply a recent event that caused about 3 m of left-lateral displacement. Furthermore, a 2-km length of the fault examined in May 1969 may have been active about that time, because fresh en echelon cracks with as much as 4 mm of left-lateral displacement crossed active channels of ephemeral streams.

Most of the surface trace of the Garlock fault is in alluvium, and it shows repeated movement along the same line or narrow zone. However, in bedrock exposures, where a longer time record of faulting is preserved, multiple, subparallel fractures form zones tens to hundreds of meters wide. In some places, as along

the prominent mountain front northeast of the town of Mojave, the active trace has migrated progressively across such a zone, away from the upthrown block. In the Tehachapi Mountains to the southwest, on the other hand, the most recent displacement appears to be distributed across much of the width of a similar zone.

#### **Borrego Mountain, Calif., earthquake of 1968**

Continuing investigation by M. M. Clark of the breaks formed by the Borrego Mountain earthquake of April 8, 1968 in southern California, revealed post-earthquake right-lateral and vertical creep of as much as 10 cm and the creation of some new tectonic fractures. Many surface breaks in zones of continued or renewed movement soon enlarge to gaping fissures as much as 2 m wide and 4 m deep, by collapse following inflow of surface water runoff during infrequent periods of heavy rain. Thus freshly collapsed fissures are excellent indications of current or very recent tectonic movement. Several preearthquake fissures have also been recognized in the fault zone, one of which apparently opened just before the earthquake.

For the most part, the 1968 fractures traverse Pleistocene lake beds and alluvial sands, muds and gravels, some of which are moderately to tightly folded in this region. Study by R. V. Sharp and Clark revealed that within a few tens of meters of the fault, the strike of nearly all folded strata swings to become parallel to the fault and dips increase to vertical, suggesting appreciable drag at the fault.

Earthquake effects of engineering importance observed after the Borrego Mountain earthquake were studied by T. L. Youd and R. O. Castle and compared with effects reported for previous earthquakes of similar character and magnitude. They concluded that: (1) the width and complexity of the pattern of surface ruptures were greater than previously reported for similar earthquakes; (2) the locations of newly formed ruptures could not have been closely predicted over more than perhaps half their extent; (3) Modified-Mercalli scale (M.M.) damage intensities were governed as much by ground conditions as by proximity to the epicenter; and (4) M.M. intensities deduced from structural damage were, in general, considerably lower than those deduced solely from ground effects.

## **ENGINEERING GEOLOGY**

### **Seismic response of soft sediments**

A theoretical study of the seismic response of soil layers underlain by sloping rock boundaries was made

by Houshang Dezfulian and H. B. Seed<sup>89</sup> (graduate student and professor, respectively, University of California, Berkeley, Civil Engineering Department). The study, which was supported by the U.S. Geological Survey, provides an analytical basis for evaluating the effects of inclined boundaries between wedge-shaped deposits of soft sediments and underlying relatively stiff sediments or bedrock. Such conditions typically exist under the marshlands of San Francisco Bay. The study indicated that inclined boundaries of firm materials beneath soft sediments cause substantial lateral variations in seismic accelerations at the ground surface, but only limited variations in frequency characteristics. The distribution of such accelerations varies widely and depends on the inclination of the underlying boundary. In addition, inclined subsurface boundaries may cause damage effects to be focused during earthquakes.

### **Earth tremors caused by coal mining at Somerset, Colo.**

More than 6,000 earth tremors were recorded in the Somerset coal-mining district in Delta and Gunnison Counties, Colo., during the last half of 1969 by a seismic station installed July 11 on the ground surface near the Somerset mine. Of this total, 710 tremors had estimated Richter magnitudes between 1 and 2, and 17 had estimated magnitudes between 2 and 3. A study of this seismic activity by C. R. Dunrud indicated that stresses induced by mining operations are a major cause of the earth tremors. Most tremors originate near the mine workings, and some of small magnitude recorded by the seismograph could be directly correlated with bumps felt and heard within the mine. Tremors are also more numerous on workdays than on weekends when the mines are idle. On the other hand, natural stresses apparently cause large changes unrelated to mining in the long term level of seismic activity near the mine workings, and also cause tremors which are probably centered many miles from the mines.

The recorded pattern of seismic activity resembles that of the Sunnyside coal-mining district of east-central Utah. However, earthquake frequency seems to be more directly controlled by coal production at Somerset, and tremors are fewer in number and of smaller magnitude. These differences may be explained by the rocks associated with the coal at Somerset, which are less competent than those at Sunnyside and seem to respond more quickly to mine-

<sup>89</sup> Dezfulian, Houshang, and Seed, H. B., 1969, Seismic response of soil deposits underlain by sloping rock boundaries: Univ. California, Berkeley, Earthquake Eng. Research Center, Rept. EERC 69-9, 24 p., 29 figs., 3 tables.



induced stresses. In addition, the Somerset mines have not been producing large daily tonnages for as long a period of time.

## URBAN AND SPECIAL ENGINEERING STUDIES

### Engineering geology problems related to oil production in Alaska

The recent discovery of vast oil reserves at Prudhoe Bay in northeastern Alaska has focused attention on geologic-environmental factors unique to the Arctic which pose special engineering problems. Permafrost, or perennially frozen ground, is the most significant of these factors. Because of an urgent need for information, O. J. Ferrians, Jr., Reuben Kachadoorian, and G. W. Greene (r0104) prepared a report which summarizes the present state of knowledge concerning permafrost and related engineering problems in Alaska. The report was conceived, written, reviewed, edited, and published during a period of 3 months.

An 800-mile-long pipeline has been proposed for transporting hot crude oil from the oil fields on the Arctic coast to Valdez, a year-round ice-free port on Alaska's south coast. Because initial plans included burial of the pipeline, some serious engineering problems were anticipated. A study of the thermal effects on permafrost of a heated pipeline was undertaken by A. H. Lachenbruch (r0443). Two of the problems examined in this study are the removal of support from the pipe as a result of the thawing of the adjacent permafrost, and the creation of potentially mobile slurries by the liquefaction of permafrost in unconsolidated materials of low permeability.

Potential geologic hazards along the southern part of the proposed pipeline route were reviewed by Ernest Dobrovolsky, H. R. Schmoll, and L. A. Yehle (r0663). The potential hazards that were considered and located on a map of the pipeline route include disruption of the ground by movement along faults and by earthquakes, floods, surging glaciers, snow avalanches, slope failures, and the effects of thawing of permafrost.

### Surface deformation at some oil and gas fields in the United States

A review by R. F. Yerkes and R. O. Castle<sup>90</sup> of known examples of surface deformation associated in time and space with operation of oil and gas fields in the United States has documented 26 cases of differen-

tial subsidence, 3 of measured horizontal displacement, and 12 of surface faulting associated with 30 fields in California and 11 in Texas. All subsidence depressions are more than twice as large as the producing areas and are centered over them. Horizontal displacements accompany subsidence and are directed toward the center of the depression. Surface faulting commonly is on the periphery of the depression, normal, and downthrown toward the depression. A centrally located low-angle reverse fault at the Buena Vista field of southern California is a major and unique exception and previously has been attributed to tectonism. Strain profiles across typical subsidence depressions show intense compression within the area of maximum subsidence and an annular zone of tension at the periphery.

Salient examples of deformation at oil and gas fields are as follows: differential subsidence of more than 29 feet occurred between 1936 and 1966, and horizontal displacement of 11.94 feet occurred between 1937 and 1966 at Wilmington in southern California; displacement of more than 2 feet occurred between 1930 and 1950(?) on a normal peripheral fault at the Saxet field near Corpus Christi, Tex.; and there was more than 2.42 feet of displacement between 1932 and 1967 on the low-angle reverse fault at Buena Vista. Subsurface compaction similar in amount to surface subsidence has been monitored at Wilmington, Calif., during a measured decline in reservoir pressure, and while oil was being produced from the zones undergoing compaction.

A detailed analysis by R. O. Castle and R. F. Yerkes (r0650) of surface deformation in the Baldwin Hills, Los Angeles County, Calif., attributes the deformation largely or almost wholly to the exploitation of the spatially associated Inglewood oil field. The deformation includes well-defined differential subsidence which centers on the oil field as well as horizontal displacements directed toward the center of the subsided area. In addition, there has been earth cracking and displacement on surface faults along the eastern margin of the subsidence depression. These structural features constitute one of the most definitive examples known of surface deformation associated with oil-field operations. The maximum calculated subsidence between 1911 and 1963 was 5.67 feet, and the maximum recorded horizontal displacement between 1934 and 1963 was 2.50 feet. The maximum cumulative fault displacement was 6 or 7 inches between 1957, when contemporary faulting was first clearly recognized, and 1963. The Inglewood oil field was discovered in 1924. Examination and analysis of

<sup>90</sup> Yerkes, R. F., and Castle, R. O., 1970, Surface deformation associated with oil and gas field operation in the United States: *Internat. Assoc. Sci. Hydrology*, v. 1, Pub. 88, AIHS, p. 55-66.

changes in the local ground-water regimen, the history of surface loading and unloading, and local tectonic activity indicate that these phenomena cannot be more than incidentally related to the surface deformation. A small part of the local elastic strain pattern may have resulted from tectonic activity, but this part should have had an insignificant effect in comparison with the strain pattern generated by the compaction of zones from which oil has been withdrawn.

The volume of subsidence in the Inglewood oil field in the Los Angeles Basin, Calif., has increased approximately linearly with cumulative liquid production, according to a report by R. O. Castle, R. F. Yerkes, and F. S. Riley.<sup>91</sup> Similar but less completely documented relations apparently exist for three Venezuelan fields and for the Wilmington and Huntington Beach fields, California. The observed correlation conforms with theoretical expectations if the reservoir is considered to be a tightly confined artesian system in which production must be derived entirely from liquid expansion and reservoir compaction, and if, further, the compressibilities of the liquid and of the reservoir skeleton remain approximately constant.

The relationship between subsidence and pressure decline in wells at Inglewood is, in contrast, profoundly nonlinear. The reason for the poor correlation is believed to be that pressure declines measured at individual wells are not representative of the average decline over the field as a whole.

#### **Geologic mapping of utility trenches at Boulder, Colo.**

As a consequence of the open-file release of the first two engineering geologic maps<sup>92</sup> of the Boulder area by the Denver Regional Council of Governments cooperative project, officials of the City of Boulder adopted a suggestion made by M. E. Gardner (deceased), project geologist. Utility trenches and other large excavations will henceforth be geologically mapped for the city by graduate students of the Department of Geology, University of Colorado, under the supervision of faculty members. This program, possibly the first of its kind in the United States, will permit revision and refinement of the maps, and is especially timely because of a proposal by the City to bury all above-ground utility lines in the future.

<sup>91</sup> Castle, R. O., Yerkes, R. F., and Riley, F. S., 1970, A linear relationship between liquid production and oil-field subsidence: *Internat. Assoc. Sci. Hydrology*, v. 1, Pub. 88, AIHS, p. 162-173.

<sup>92</sup> Gardner, M. E., 1968, Preliminary report on the engineering geology of the Boulder quadrangle, Boulder County, Colorado: U.S. Geol. Survey open-file rept., map, explanation, 3 tables.

— 1969, Preliminary report on the engineering geology of the Eldorado Springs quadrangle, Boulder and Jefferson Counties, Colorado: U.S. Geol. Survey open-file rept., map, explanation, 3 tables.

#### **Debris flows in southern California**

The heavy rains of January and February 1969, caused many fast-moving debris flows in the hill and mountain areas of southern California. Investigations by R. H. Campbell (r2215) showed that at least 15 fatalities resulted from debris flows caused by slides of saturated soil on slopes immediately adjacent to dwellings. All the debris flows in January occurred during downpours after about 10 inches of rain had already fallen in the previous 8-day period.

#### **Depth of rock stresses caused by daily temperature changes**

Diurnal thermal changes on the surface of a massive rock body generate stresses that can be detected well below the depth to which the temperature changes penetrate. This has been demonstrated by data from borehole stress probes installed by T. C. Nichols, Jr., and F. T. Lee in the Mt. Airy Granite of Stuckey and Conrad<sup>93</sup> at Mt. Airy, N.C. Probes installed at depths of 1, 3, 7½, and 27 feet were monitored for a week in August 1969. The probe at 1-foot depth showed large responses to thermally induced stress changes, whereas the probe at 3 feet showed small responses. The daily temperature changes occur only down to a depth of 4 feet, and most of the change takes place in the first foot. The probe at 7½ feet showed diurnal stress changes opposite in sense to the responses recorded on the probe at 1 foot. This suggests that thermal stresses near the surface generate opposing stresses below the depth of daily temperature changes. The probe positioned at 27 feet indicated little or no diurnal change.

A United States patent was issued in December 1969 on the borehole stressmeter used in this study and in many other rock mechanics research investigations. The inventors are T. C. Nichols, Jr., F. T. Lee, and J. F. Abel, Jr.

#### **Model studies of stress changes in rocks**

Residual stresses of significant magnitude appear to be fairly common in many kinds of rocks. The mechanical systems by which these stresses are retained are, however, poorly understood. As an aid to understanding these mechanisms, a simple physical model was constructed by D. J. Varnes that shows, in two dimensions, how an aggregate of several dozen units that simulate crystals or grains in a rock can retain internally balanced forces without exterior loads on the group. Behavior of the model can be varied by use of elastic, frictional, or viscous internal restraints, either

<sup>93</sup> Stuckey, J. L., and Conrad, S. G., 1958, Explanatory text for geologic map of North Carolina: North Carolina Dept. Conserv. and Devel., Div. Mineral Resources Bull. 71, 51 p.

alone or in combination. Time-dependent relaxation results in the spalling off of sheets and eventual disintegration of the group into individual units, simulating in a few minutes the effect of unloading or prolonged weathering on bonds between, for example, crystals of a granite that congealed under high pressure.

Laboratory model studies by J. F. Abel, Jr., show that stress changes occurring ahead of an advancing tunnel in an elastic medium that is of uniform texture and that is approximately isotropic are more complex than predicted by elastic theory. Cast acrylic, concrete, and granite were the materials used. In each of the models there was an unpredicted buildup of vertical compressive stress at a distance of approximately 2 to 3 tunnel diameters in front of the advancing tunnel face. As the tunnel continued to advance, the compressive stress decreased at about  $1\frac{1}{2}$  diameters and then began to increase again at 1 diameter in front of the advancing face. The buildup of vertical stress reached a maximum at the tunnel face which was approximately the same as predicted by elastic theory. The discovery of the initial onset of stress at 2 to 3 diameters could influence tunnel excavation methods and design.

## INVESTIGATIONS RELATED TO NUCLEAR ENERGY

### TEST-SITE EXPLORATION, DEVELOPMENT, AND RESEARCH

#### 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.

The hydrologic investigations at Pahute Mesa, NTS, are specifically designed to provide hydraulic data needed to select suitable depth intervals for excavation of chambers in large-diameter emplacement holes. Relative specific capacities were determined by R. K. Blankennagel and J. E. Weir, Jr., from injection-test data of intervals isolated by in-

flatable packers in deep drill holes. Conversion of relative specific capacity to hydraulic conductivity, using an empirical conversion factor, provided usable predictions of the maximum inflow of water into underground chambers. Pumping equipment to assure the safety of miners during chamber construction was selected from these predictions.

Some circumstances require that emplacement chambers be kept dry for extended periods of time. The sustained influx of water, with continuous removal from the chamber, is significantly less than the empirically determined maximum. It therefore has become important to provide realistic estimates of the nonsteady, gradually declining discharge. W. W. Dudley, Jr., and V. R. Baker used a method originated by Cooper, Bredehoeft, and Papadopoulos<sup>94</sup> to determine transmissivities and storage coefficients from slug-injection test data. Knowledge of these parameters allows the calculation of nonsteady inflow to underground chambers. For relatively impermeable, fractured volcanic rocks at Pahute Mesa, the relative specific capacity ( $R_{sc}$ ), the transmissivity ( $T$ ), and the storage coefficient were found to vary somewhat with the hydraulic pressure applied to the tested zone. In the commonly used 3- to 4-minute time period the empirical correlation,  $T = 5.2 \times 10^3 R_{sc}^{1.4}$ , may be used for estimates of  $T$ . After 30 minutes of injection, however, the relationship was found to be  $T = 8.2 \times 10^3 R_{sc}^{1.4}$ .

The development by Blankennagel and Weir, of an areal map of hydraulic potentials beneath Pahute Mesa identified a distinct barrier to the movement of ground water. The barrier is oriented north-south and coincides with the probable subsurface western boundary of the Silent Canyon caldera. Seismic studies after the BENHAM and JORUM nuclear events have shown that explosion-triggered aftershocks originate along that same linear zone.

Stratigraphic studies by D. L. Hoover and E. N. Hinrichs at the Nevada Test Site indicate that ash-fall tuff and tuffaceous sediments deposited on steep paleotopography and buried by welded tuffs have patterns of distribution that differ greatly from those of the overlying welded tuff. Recognition of these differences has aided in the planning of exploratory programs that are designed to determine the best locations for future nuclear tests. On Rainier Mesa, primary paleovalleys in ash-fall tuffs 1,000 feet beneath the present surface are parallel to but offset as much as 1,000 feet from other paleovalleys that are defined near the top

<sup>94</sup> Cooper, H. H., Jr., Bredehoeft, J. D., and Papadopoulos, I. S., 1967, Response of a finite-diameter well to an instantaneous charge of water: *Water Resources Research*, v. 3, no. 1, p. 263-269.

of the stratigraphic section by primary dips in the welded tuff. Subsidiary paleovalleys in the buried ash-fall tuffs have trends  $45^{\circ}$  to  $60^{\circ}$  from their higher counterparts in the welded tuffs. On Aqueduct Mesa, preliminary data indicate that the trends of the primary paleovalleys in tuffs 1,400 feet beneath the surface probably diverge  $120^{\circ}$  to  $150^{\circ}$  from the primary paleo-valley on which the surface welded tuff was deposited.

#### CENTRAL NEVADA

The U.S. Atomic Energy Commission detonated the first underground nuclear explosion in the central Nevada test area, in Hot Creek Valley, northern Nye County, in January 1968. The U.S. Geological Survey has explored potential test sites by drilling, geologic mapping, geophysical surveys, and hydrologic studies. The valley areas are of prime interest because of the thick accumulation of alluvium and volcanic rocks.

The first and principal objective of the Geological Survey's program was to determine the geologic and hydrologic suitability of the Hot Creek and Big Sand Springs Valleys for underground nuclear testing. Geologic study, deep exploratory drilling, and the seismic response measured from one nuclear underground test demonstrated this suitability.

Geologic study by E. B. Ekren and others in Hot Creek Valley, Big Sand Springs Valley, southern Pancake Range, and the Morey Peak area of the Hot Creek Range in central Nevada outlined an area of volcanic subsidence about 40 miles long (north to south) and 30 miles wide (east to west). The area contains several nested superimposed and, in places, overlapping cauldrons. Drilling for site exploration revealed that the largest and oldest of the cauldrons is filled with at least 6,000 feet of quartz latitic ash-flow tuff. The definition of a large composite cauldron complex resulted in an extension of the favorable area available for underground test sites.

According to G. A. Dinwiddie, the hydrologic study of the region indicates that the ground-water movement generally is eastward from Hot Creek and Little Smoky Valleys toward discharge areas in Railroad Valley. These results are supported by geochemical data and interpretations. Results of deep-hole hydraulic testing indicate that intervals of high hydraulic conductivity in volcanic rocks are related to fractures and that some intervals of welded tuff have sufficiently low hydraulic conductivity at some places to allow construction of chambers for underground nuclear tests at depths of 5,000 feet or more below the water table. The results further indicate that the hydraulic potential in the deep hydrologic system is above land sur-

face at some places in Hot Creek Valley and that this deep system probably is associated with underlying carbonate rocks.

#### AMCHITKA ISLAND, ALASKA

##### Studies of the general area

The U.S. Geological Survey is continuing to study the geology and hydrology of Amchitka Island in order to assist the U.S. Atomic Energy Commission in the development of the island for future underground nuclear explosions. An aerial photography study of Pleistocene and Holocene marine terraces on islands of the western Aleutians by R. H. Morris showed that, with the possible exception of Attu Island, neither vertical differential movement nor tilting of islands or island groups in the last 240,000 years has been detected. A brief marine geophysical survey showed that the submarine Aleutian slope south of Amchitka has little unconsolidated sediment lying on it that might give rise to large submarine landslides as a result of the nuclear tests.

C. H. Miller, G. D. Bath, and W. D. Quinlivan found that over a 15-mile interval of central Amchitka average densities to a 5,000-foot depth increase laterally from 2.22 to 2.55 g/cm<sup>3</sup> and correlate with an area of low-gravity gradient. On northwestern Amchitka, either a wedge of high-density breccia or a high-angle fault will explain a 23-mgal anomaly. More speculative interpretations include considerations of small changes in near-surface densities to explain six local gravity anomalies, and a larger change at depth to explain an extensive regional anomaly on southeastern Amchitka.

Measurements by W. C. Ballance show that composite static water levels in five exploratory holes on Amchitka Island range from about 20 to about 200 feet below land surface. Static water levels in isolated zones range from about 40 to about 400 feet below land surface. The hydraulic potential decreases with depth, and the water-level gradients range from 113 to 405 feet per mile in shallow zones and from 28 to 98 feet per mile in deep zones. The chemical analyses of water samples obtained from the exploratory holes indicate an increase in salinity with depth. The hydraulic conductivity of the rocks is very low, except in zones of intense fracturing. At all but one of the exploratory sites, chambers for nuclear tests could be constructed without severe problems of water inflow. The bulk porosity of the rocks ranges from 1 to 38 percent and the effective porosity is about 1 percent of the bulk porosity. Most of the permeability is in frac-

tures, and the degree of permeability is dependent upon rock type and structure.

#### **MILROW nuclear test**

An underground nuclear test—MILROW—of about 1 megaton was fired successfully in October 1969 as a "calibration" test; the geologic effects were very minor. Geologic effects were limited to rockfalls, slumping, and cracking of manmade features. Minor movement on two small faults less than 1 mile from GZ (ground zero) was observed. The chimney collapsed at about H+37 hours forming an irregular rectilinear surface depression about 1,700 feet across and as much as 20 feet deep at the center.

Geodetic surveys showed vertical movement ranging from one-half inch to one-half foot on four faults—excluding the Rifle Range fault—within  $2\frac{1}{2}$  miles of GZ, and slight horizontal movement on a few faults including the Rifle Range fault within  $3\frac{1}{2}$  miles of GZ. All such movements were far less than predicted and less than those observed at the Nevada Test Site for similar sized events.

Analysis of Clevenger Creek stream-flow records by W. C. Ballance indicates considerable water is being stored upstream in the vicinity of the MILROW site. The retention of water in this area is probably caused by the change in surface gradient resulting from subsidence at the MILROW site and by the chimney intercepting shallow ground water that normally would be discharged to Clevenger Creek. Two ponds were faulted and tilted by the sinking of the ground surface near GZ, and subnormal stream flow indicates that a considerable volume of surface water is now filling the chimney. On the basis of this evidence it is now estimated that the chimney will fill with water in about 1.4 years, at which time the ground water will continue its normal preshot movement.

#### **FLOWSHARE PROGRAM**

The U.S. Geological Survey evaluates the geologic and hydrologic environment of sites to be used for the U.S. Atomic Energy Commission's FLOWSHARE Program. Specialized geologic and hydrologic studies by the Geological Survey also provide data required both for technical feasibility and for safety of proposed FLOWSHARE nuclear detonations. Recommendations and suggestions to the Commission are made outlining further studies and tests needed to resolve problems in using nuclear explosives effectively and safely in various environments. Project GASBUGGY in New Mexico and Project RULISON in Colorado are FLOWSHARE projects designed to study the economic and technical feasibility of using nuclear explosives to stimulate

production of natural gas from low-production gas-bearing formations. Some other examples of proposed FLOWSHARE projects are Project SLOOP—the in situ leaching of a copper ore body; Project KETCH—underground storage of natural gas; and Project AQUARIUS—for water management.

#### **Project GASBUGGY**

The Project GASBUGGY nuclear experiment of 26 kilotons yield was detonated at a depth of 4,240 feet below ground level at the GASBUGGY site in Rio Arriba County, N. Mex., December 10, 1967. As part of the continuing evaluation of effects of the detonation, a hole (GB-3) was drilled 4,808 feet deep at a location 250 feet northwest of ground zero during August and September 1969. When GB-3 was 3,699 feet deep, J. E. Weir, Jr., performed hydraulic tests in the Ojo Alamo Sandstone, which is about 600 feet above the point of detonation. Results of the hydraulic test of the basal part of the sandstone showed no increase in permeability owing to the detonation. Results from the postshot hydraulic test of GB-3 were comparable with the results of the preshot hydraulic testing of GB-1, which is about 100 feet southwest of GB-3.

#### **Project RULISON**

The Project RULISON nuclear experiment of approximately 40 kilotons yield was detonated at a depth of 8,425 feet below ground level at the RULISON site in Garfield County, Colo., September 10, 1969. P. T. Voegeli, Sr. and S. W. West (r1793), R. T. Hurr, W. W. Wilson, F. A. Welder, and R. L. Emerson (r0779), and J. D. Larson and W. A. Beetem (r0786) studied the hydrology in and near the RULISON site. Voegeli concluded from studies of preshot and postshot hydrologic conditions that the detonation did not significantly or permanently affect wells, springs, streams, shallow aquifers, or reservoirs in or near the RULISON site.

#### **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 should not exceed environmental considerations. The research includes (1) close-in short-time effects that pertain largely to containment of the explosion products within the test media, and (2) long-range and (or) long term effects that might result in adverse conditions outside the immediate vicinity of the explosion.

**Close-in effects**

*Physical properties of test media.*—Analyses of compressional velocity, shear velocity, and density data obtained from geophysical logs and from laboratory core tests indicate that it is probable that in many volcanic rock areas in which many nuclear explosions take place, like those of Nevada Test Site, it may be possible to establish a relationship between compressional velocity and shear velocity, dynamic moduli, acoustic impedance, and shear and compressional reflection coefficients. This implies that a simply measured parameter, such as compressional velocity, may be sufficient to reliably estimate most acoustic parameters of interest to geophysicists in many unfamiliar lithologic provinces.

Precise densities were determined by D. L. Healey for some test media in the Nevada Test Site and in Hot Creek Valley from measurements using a special borehole gravity meter and standard gravity meters in large-diameter boreholes and a vertical shaft. The densities are used for interpretation of regional gravity surveys as well as for control in evaluating effects of explosions in different media. Three holes and one shaft penetrated alluvium, and six holes penetrated Tertiary volcanic rocks on Pahute Mesa. The weighted average densities for alluvium—1.94, 1.69, 2.22 and 2.05 g/cm<sup>3</sup>—show marked variation; the density of five of the six holes in Tertiary volcanic rocks ranged from 1.98 to 2.06 g/cm<sup>3</sup>. An important nonwelded ash-flow tuff, which was penetrated by the sixth hole, averaged only 1.51 g/cm<sup>3</sup>, and was selected for the site of a special seismic response experiment. Density logs were interpreted for 10 additional holes. In Yucca Flat the mean density of more than 7,000 feet of alluvium is 2.01 g/cm<sup>3</sup>, and in Hot Creek Valley the mean of more than 18,000 feet is 2.18 g/cm<sup>3</sup>.

A gravity survey on Amchitka Island provided additional density information on the Tertiary volcanic and intrusive rocks that are within about 5,000 feet of the surface. The survey was supplemented with densities from 359 surface samples, 142 drill-core samples, and 23,000 feet of gamma-gamma logs from four drill holes. In situ densities average 2.48 g/cm<sup>3</sup> for 2,650 feet of andesitic and basaltic flows, dikes, and sills; 2.32 g/cm<sup>3</sup> for 6,200 feet of volcanic breccia, 2.51 g/cm<sup>3</sup> for 680 feet of intrusive rock; and 2.24 g/cm<sup>3</sup> for 200 feet of volcanic sandstone, siltstone, and tuff breccia.

*Mechanism of collapse.*—F. N. Houser has been studying the mechanism of collapse of nuclear explosion cavities at Nevada Test Site because of the effectiveness with which collapse stops dynamic eruptions

of detonation gases that are escaping to the atmosphere. Such eruptions have been infrequent in the past and they have happened for a variety of reasons unrelated to collapse.

To date, the studies have been devoted mainly to the subsidence of the ground surface in the desert alluvium of Yucca Flat caused by collapse of volcanic rocks and (or) alluvium into the explosion cavities. The sinks formed in this way are as much as 200 feet deep and 800 feet in radius; they have shapes that are commonly variations of inverted cones or sectors of spheres (Houser, r0291). The depth of burial of the explosion cavity in alluvium, relative to its size, affects the profile of the sinks, the height of chimneys for collapses not extending to the surface, and, to an extent, the likelihood that later surface subsidence will occur (Houser, r2573).

A working model of collapse includes: (1) maintenance of the explosion cavity until main collapse occurs; (2) a two-phase collapse taking place in several seconds or several tens of seconds, culminating in the drop of a central mass of alluvial material that initiates formation of the sink. The shape, size, and distance of vertical drop of this alluvial plug strongly influences the size and form of the sink.

*Onsite detection.*—In fiscal year 1966 the Geological Survey directed two field trials—Project ARKOSE and Project BRECCIA—for the VELA On-Site Inspection Program on behalf of the Advanced Research Projects Agency of the U.S. Department of Defense. These field trials were designed to test methods of verification of underground nuclear explosions.

H. T. Shacklette, J. A. Erdman, and J. R. Keith have continued research in promising botanical techniques for onsite inspections. Studies of the effects on vegetation of shock produced by underground nuclear explosions at sites in the Aleutian Islands, New Mexico, and Nevada reveal that certain plant species are potentially useful in detecting explosions. At some locations the effects of shock could be detected at a greater distance from the source by using plant sensors than by using geologic materials. Many responses of plants to shock can be used to determine, with various degrees of accuracy, the date when the shock was produced. Other types of manmade or natural disturbances may, at suitable locations, be indicated by their effects on plant communities, and these effects may persist for long periods of time.

**Long-range and (or) long-term effects**

*Earthquakes and nuclear explosions.*—Analysis by F. A. McKeown, D. D. Dickey, R. C. Bucknam, and G. E. Brethauer of photographic, geodetic, geologic,

and seismologic information acquired by the U.S. Geological Survey and several universities permit some reasonably firm conclusions about earthquakes triggered by nuclear explosions. Most of the conclusions had been suspected or inferred for several years, but supporting evidence was weak.

High-speed motion picture photography taken by Lawrence Radiation Laboratory and by Edgerton, Germeshausen, and Grier, Inc., at the request and under the direction of the Geological Survey has shown that movement occurs on some faults as soon as the arrival of the first seismic waves reach the fault (McKeown and Dickey, r0290). Geologic mapping, as exemplified in a report by Bucknam (r0468), shows that movement on preexplosion faults occurs along them for as much as 8.5 km and that permanent displacements, both vertical and lateral, are as much as 1 m. Further, the direction of displacement is always the same as the direction of the last tectonic displacement.

Dickey (r0470) showed from geodimeter surveys that strains from the BENHAM nuclear explosion, and probably the accompanying fault movement, decrease to less than  $10^{-5}$  at about 15 km. The decrease in strain with distance is not always regular; local faults that transect the geodimeter survey lines cause local increases in strain that may not be elastic if slight movement occurred on the faults.

Preliminary estimates of the depth of faulting made by Brethauer and Bucknam using dislocation theory indicate that the depth of faulting that accompanies nuclear explosions ranges from 0.5 to 2 km. This is considerably shallower than the maximum depths of aftershocks from nuclear explosions (R. M. Hamilton and J. H. Healy, r1320). Further, the aftershocks may or may not occur on the same faults along which movement is known to occur immediately after an explosion. The aftershock zone identified for one part of Pahute Mesa at Nevada Test Site is along the ring-fracture zone of a buried Tertiary caldera of the Silent Canyon volcanic center.

Using a simple physical model, a step function of pressure within a spherical cavity in a perfectly elastic medium, one can determine the source parameters of two explosions at the same location from distant spectral ratios. For the SALMON and STERLING events the apparent seismic source radii were calculated by J. H. Healy and M. E. O'Neill to be about 170 and 29 m. The pressure ratio of SALMON to STERLING is about 4.

The BENHAM underground nuclear explosion at the Nevada Test Site initiated an earthquake sequence numbering about 1,000 events over magnitude 1 and extending out to 13 km from ground zero. Analysis of

the first-motion pattern of 100 of the larger events revealed that two fault mechanisms were operative—strike slip and dip slip—but that they had in common a northwest-southeast-oriented tension axis. This direction is consistent with that found in earlier studies of natural earthquakes and with that determined from studies of the surface-wave radiation pattern from earlier explosions. These results coupled with observations of surface faulting along natural faults indicate that the explosions stimulate the release of natural tectonic strain energy. The JORUM explosion caused extension of the BENHAM seismic zone by about 3 km, but produced a much lower level of earthquake activity. This effect is consistent with the idea that strain energy is released by the explosions (R. M. Hamilton and J. H. Healy, r1320; R. M. Hamilton, F. A. McKeown, and J. H. Healy, r1737).

*Response of well-aquifer systems.*—Fluid pressures in several wells sealed with inflatable packers have been monitored during and after nuclear detonations in Nevada, Colorado, and Alaska in the past year. Sufficient data have been gathered and analyzed by W. W. Dudley, Jr., and L. E. Wollitz to predict within a factor of two the fluid overpressures generated by Nevada nuclear explosions. The equation that predicts the dynamic-phase overpressure in bars, for observed distances  $4 < R < 120$  km, is  $+H = 3.2W^{0.33}R^{-1.32}$ , where  $H$  is pressure expressed in meters of water,  $W$  is the device yield in kilotons, and  $R$  is the distance from the explosion in kilometers. At distances of 8 to 23 km the dynamic-phase overpressures resulting from the MILROW event on Amchitka Island, Alaska, were described by  $+H = 2.1 \times 10^1 W^{0.33} R^{-1.54}$ . The Alaska results were greater by a factor of about 4 than were the Nevada results. Data from the RULISON event in Colorado were not sufficient to develop a regression equation.

One observation well that penetrates nearly 4,200 m beneath Pahute Mesa at the Nevada Test Site has shown sustained pressures of several bars during the first few hours after detonations 3 to 8 km away. In addition to its proximity to several event sites, the depth and geologic setting of this well may also be responsible for its behavior. The well is located within, but near the western boundary of, the Silent Canyon volcanic center. The seismic aftershocks resulting from several tests on Pahute Mesa have occurred in the same general area.

Pressure transducers, suspended below static water level in open wells and mated to high-speed recording oscillographs, have been used to measure rates of water level change from which surges in wells are calculated. Cyclic surging with periods of one to three



seconds and magnitudes as great as 100 gpm have been observed 120 km from nuclear tests of high to intermediate yield.

**RULISON seismic response.**—Effects of the RULISON nuclear shot were measured by C. R. Dunrud near Somerset coal mine, Colorado, using a seven-station seismic monitoring network, which was in operation from August 28 to September 16, 1969. This network was installed to monitor earth tremors that were reported to be increasing in the last few years at the same time that coal production increased, and also to supplement a geologic study of coal mine bumps that is underway in the district. Based on simple harmonic-motion analysis, the peak ground displacement amplitude, peak velocity, and peak acceleration of the RULISON nuclear explosion of September 10 were measured at  $38\mu$  (0.0038 cm), 0.10 cm/sec, and 0.0025 *g* (gravity) (2.4 cm/sec<sup>2</sup>), respectively. No significant change in seismic activity was recorded by the seven-station network in the mining district for the duration of the recording period after the shot. Most of the tremor hypocenters plotted near the active mining sections apparently resulted from mine-induced stresses. Miners reported no change in mining conditions after the shot. Of considerable interest is the fact that loose rocks, ranging in weight from a few hundred pounds to many tons, perched on steep slopes were not disturbed—even in areas where seismic motion was noticeable.

**Stress changes.**—Changes in stress were measured with U.S. Geological Survey three-dimensional borehole stress probes<sup>95</sup> at shallow depths on Pahute Mesa, Nevada Test Site, and on Amchitka Island, Alaska, by T. C. Nichols, Jr., and F. T. Lee, assisted by Verne Hooker (U.S. Bureau of Mines). In addition, in situ absolute stress measurements were made on Amchitka Island. Large and small changes in stress occurred over periods of days at both the Nevada and Amchitka sites. The JORUM nuclear event appeared to have caused large decompressional stress changes at two sites on Pahute Mesa. On Amchitka, decompressional changes in stress occurred at one site and compressional changes in stress occurred at another site sometime within a seven-week period beginning three days after the MILROW nuclear event. In situ measurements of absolute stress indicate that at shallow depths on Amchitka the stress is less than 200 psi.

The larger changes in stress after the nuclear events may indicate that either "locked in" strain energy in the rock was activated or tectonic stress was altered.

<sup>95</sup> Nichols, T. C., Jr., Abel, J. F., Jr., and Lee, F. T., 1968, A solid-inclusion borehole probe to determine three-dimensional stress changes at a point in a rock mass: U.S. Geol. Survey Bull. 1258-C, p. 1-20.

### Hydrology of small nuclear test sites

The nuclear explosive for Project RULISON, in Garfield County, Colo., was detonated successfully September 10, 1969, at a depth of 8,425.5 feet below ground level and was reported by P. T. Voegeli, Sr., and S. W. West (r1793) to have been completely contained. In no case was there any indication that the streams or water-bearing formations in the vicinity of the site had been permanently impaired as a result of the detonation. Seismic effects of the nuclear detonation caused a hydrostatic pressure pulse in two monitored wells. In one well, about 3,660 m (12,000 feet) from SGZ (surface ground zero), the hydraulic pressure below the packer exceeded the response limits of the 0 to 100-*psia* pressure transducer. In the second monitoring well, about 6,100 m (20,000 feet) from SGZ, a maximum pressure increase of 0.398 *psi* (equivalent to 21.0 cm or 0.688 foot of water) and a maximum decrease of 0.321 *psi* (22.6 cm or 0.742 foot of water) were recorded at the time of the detonation. The magnitude of the pressure increase in the second monitoring well is not significant in terms of probable well damage or aquifer deformation. In response to the detonation, the discharge of Battlement Creek recorded at the U.S. Geological Survey gaging station increased slightly, immediately after the detonation. The discharge at the gaging station 1 hour and 30 minutes after the detonation increased abruptly from 4.5 to 14 cfs, and then began a gradual decline.

Analyses of water collected after the shot, from 21 surface-water sampling points in and near the RULISON site, indicated that the nuclear detonation had no effect upon the chemical characteristics of the water. Analyses of spring water collected after the shot also indicated that the nuclear detonation had no permanent effect upon the chemical characteristics of the water.

Results of hydraulic testing by J. E. Weir, Jr., in hole GB-3 (250 feet northwest of the emplacement hole), a postdetonation offset boring at the GASBUGGY site, Rio Arriba County, N. Mex., showed no apparent increase in permeability of the lower Ojo Alamo Sandstone as a result of the GASBUGGY nuclear detonation December 10, 1967. The base of the Ojo Alamo Sandstone is almost 600 feet above the point and about 250 feet above the top of the rubble chimney formed after the GASBUGGY detonation.

Project WAGON WHEEL, in Sublette County, Wyo., is to be an experiment in the stimulation of a natural-gas reservoir by means of a nuclear explosive. Voegeli reported that a water well (2,500 feet deep) was drilled for hydraulic test purposes at the site. The following information was obtained: The well produced 51.7

gpm from 19 gun-perforated intervals between depths of 130 feet and 2,432 feet. The transmissivity of the sandy intervals open to the well was about 2,200 gpd per ft. Water was produced from the WAGON WHEEL exploratory hole, 100 feet east of the water well, during a swabbing test of the interval between 6,868 feet and 7,140 feet. No water was produced during a drill-stem test of the interval between 7,275 feet and 7,400 feet in the exploratory hole.

### 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 would also be applicable to predicting the fate of radioactive materials that might be released to the hydrologic environment in the event of an accident.

Part of the research 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 a study of the occurrence and transport of radionuclides derived from the U.S. Atomic Energy Commission's Hanford reactors, D. W. Hubbell, J. L. Glenn, H. H. Stevens, and G. A. Lutz observed from frequently collected water-sediment samples in the Columbia River estuary at Astoria, Oreg., that the concentration of chromium-51 in solution increases during the fall and early winter to a maximum in February and March, then decreases to a minimum in August. Concentrations of zinc-65 in solution follow a similar pattern, but they are roughly two orders of magnitude lower, and their seasonal variation is about four times greater than those for chromium-51.

Seasonal variations of concentrations of chromium-51 and zinc-65 associated with particulate matter, however, are different from each other and are not in phase with the concentrations in solution. Chromium-51 appears to be highest during August and September and to remain relatively constant at other times of the year. Zinc-65 concentrations vary greatly seasonally (sixfold to sevenfold) and are highest during April and May and lowest during November and December. These general temporal trends exhibited by chromium-

51 and zinc-65 at Astoria are similar to comparable trends at Vancouver, Wash., except during the late summer when the variations of chromium-51 associated with the particulate matter may be different.

On the basis of: (1) several simplifying assumptions, (2) data on the average annual transport of radionuclides and suspended sediment for the Columbia River at Vancouver, and (3) a calculated inventory of zinc-65 in the estuary, Hubbell and Glenn computed that about 30 percent of the fine sediment that enters the estuary is retained there.

#### Contamination of ground water by burial of a nuclear auxiliary powered device

A SNAP (Systems for Nuclear Auxiliary Power) device is a thermoelectric generator that utilizes radioactive material as its power source; it is presently being used to supply energy to orbiting satellites. D. B. Grove (r2035) made a theoretical analysis, on behalf of the U.S. Atomic Energy Commission and in collaboration with the Sandia Corp., of the extent of radioactive contamination of ground water that could result if such a device should accidentally plummet to and become buried in the earth's surface. Equations were developed which could be used to estimate the concentration of an ion in the ground-water environment as a function of time and distance. Chemical models developed included the use of theoretical plates, a kinetic nonequilibrium concept, and an equilibrium concept.

### 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, such as faulting, seismic activity, flooding, availability of water for cooling, and foundation conditions, as well the potential extent of contamination of water resources that could occur through the operational or accidental release of radionuclides.

During the year, P. J. Carpenter and H. H. Waldron evaluated the geologic and hydrologic aspects of 17 proposed nuclear powerplant sites.

In a study of extreme hydrologic events and their effects on nuclear facilities, P. H. Carrigan, Jr., has applied an order-statistic model to the study of floods at the National Reactor Testing Station, Idaho. He finds that the probability that the earth-filled flood-

control dam on the Big Lost River within the station boundaries will be overtopped is about 2.3 percent in any one year. By the expedient of increasing the flood-control diversion (upstream from dam) to the available spreading grounds, the probability of failure in the flood-control system can be reduced to less than 1 percent in any year. Reduction in flood hazards by further improvements in transfer of water to the spreading grounds is being studied by use of a dynamic flood routing model which utilizes a second-order autoregressive model of the flood-input hydrograph.

## FLOODS

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

### OUTSTANDING FLOODS

#### Floods of March 1968 in eastern Massachusetts and Rhode Island

Rainfall of from 4 to 7 inches during March 17-19, 1968, combined with wet antecedent conditions of the preceding spring and some runoff from snowmelt, caused damaging floods in eastern Massachusetts and Rhode Island. A report by R. G. Petersen, G. K. Wood, and R. A. Gadoury (r2045) indicates that the discharge of many streams exceeded that for the 50-year floods. Flood losses were estimated to have been \$28 million in Massachusetts and \$9 million in Rhode Island. Inundated areas along the Charles, Sudbury-Assabet-Concord, Ipswich, Neponset, Taunton, and Blackstone Rivers have been delineated on photomosaic maps.

#### Floods of July 1969 in northern Ohio

E. E. Webber reported that heavy rains of from 4 to 11 inches fell on parts of 21 counties in northern Ohio on July 4-5, 1969. An amount of more than 14 inches in 15 hours north of Wooster was officially documented. The storm and floods caused 41 deaths and more than \$65 million damage. Maximum stages and discharges of record occurred at some gaging stations, and the magnitude of peak discharges ranged as high as four times the 50-year flood.

#### Floods of July 1969 in northern Virginia

Heavy rainfall during a thunderstorm on the night of July 22, 1969, produced record floods in parts of the Washington, D.C., metropolitan area. A report by E. M. Miller and F. P. Kapinos (r2012) indicates that the unit runoff (cfs per sq mi) was the highest for the period of record at gaging stations in the Virginia suburbs. Although there was no loss of life, hundreds, of homes, stores, and apartments were flooded, principally by Fourmile Run. Estimates of damage were reported to have been from \$3 to \$5 million.

#### Floods of August 1969 in central Virginia

When Hurricane Camille became a tropical depression, the resulting rains during the night of August 19 and the morning of August 20, 1969, soaked central Virginia with up to 28 inches of rain. The rains, flash floods, and rain-induced landslides have been called the worst natural disaster in Virginia. According to J. D. Camp and E. M. Miller, the peak discharges of streams in the James, Potomac, Rappahannock, and York River basins exceeded previously known maximums. The peak discharge on Tye River near Lovings-ton was 8 times that of the previous maximum during 31 years of record. Peak discharges in the James River downstream from the Maury River exceeded the 100-year flood. The number of deaths greatly exceeded 100, and flood damage was estimated at more than \$116 million.

### FLOOD-FREQUENCY STUDIES

#### High discharge in Mississippi from Hurricane Camille tidewaters

At the Interstate Highway 10 bridge across the Jourdan River a few miles north of Bay St. Louis, Miss., the Hurricane Camille tidewater was determined by K. V. Wilson to have crested 14.7 feet above mean sea level. The water surface differential through the newly constructed 3,555-foot bridge was 1.2 feet, and the average velocity was estimated to have been 1.6 fps. Discharge at the tide crest was about 90,000 cfs, in an upstream direction, and probably exceeded 100,000 cfs during the rising tide a few hours before the crest. Before construction of the bridge, the 50-year hurricane tide stage had been estimated to be 13.2 feet, and a peak discharge of 62,000 cfs in an upstream direction had been estimated for a 10-foot stage on the rising 50-year tidal wave. The 50-year flood on the Jourdan River flowing in a normal downstream direction is estimated to be 28,900 cfs at a stage of about 4½ feet above mean sea level.

### **Photogrammetry used to develop flood profiles in Oregon**

D. D. Harris computed profiles for the 10-year, 20-year, and the December 1964 floods for a 60-mile reach of the Rogue River by using photogrammetrically measured channel cross sections and the step-backwater technique. Results indicated that the photogrammetric measurements provide suitable accuracy for defining the profiles. The computed profiles for the flood of December 1964 showed generally good agreement with documented high-water marks. The greatest differences between documented and computed elevations occur at river bends where it is expected that the actual elevations would be higher than the computed elevations on the outside of bends and lower on the inside of bends.

### **Water-surface profiles in vicinity of Belleville, Ill.**

According to J. D. Camp, water-surface profiles of the flood of June 1957 on Richland Creek and on Loop Creek near Belleville, Ill., exceeded the computed profiles for the 100-year floods by as much as 3 feet and 2 feet, respectively. The storm which caused the floods produced up to 16.5 inches of rainfall in less than 12 hours. Water-surface elevations were computed for the 25-, 50-, and 100-year floods for a 7-mile reach of Richland Creek and for a 5-mile reach of Loop Creek. Areas of inundation were also shown on a topographic map.

### **Floods in upper Des Moines River basin, Iowa**

Water-surface profiles and tabulated discharges by H. H. Schwob (r1794), furnished data for 253 miles of streams in the upper Des Moines River basin. The streams include the East and West Forks and the main stem from near Boone, Iowa, to the Iowa-Minnesota State line. Profiles include those from several past outstanding floods and those computed for the 25-year and the 50-year floods.

## **FLOOD MAPPING**

### **Floods on the Rock River in Jefferson County, Wis.**

J. O. Shearman and B. K. Holmstrom (r2138, r2139) determined the areas that would be inundated by the regional (100 years) flood for the following areas along Rock River in Jefferson County in southeastern Wisconsin: (1) A 19-mile reach of the Rock River immediately upstream from Lake Koshkonong in Jefferson County, Wis., including the cities of Fort Atkinson and Jefferson. Computed water-surface elevations for the regional flood are 7.7 to 13.6 feet higher than normal low-water elevation and 3.9 to 4.5 feet higher than the elevations of the 1959 flood (highest flood since 1929 when the elevation at Fort Atkinson ex-

ceeded the 1959 stage by 0.3 foot). (2) Around Lake Koshkonong. The estimated regional-flood elevation is about 11 feet higher than normal low-water elevation. (3) A 40-mile reach of the Rock River in northeastern Jefferson County, Wis., including the city of Watertown. Computed water-surface elevations for the regional flood are 3.5 to 11.0 feet above normal low-water elevations and about 4 feet higher at Watertown than the elevation of the 1959 flood, which was the maximum stage recorded since gaging began in 1931.

### **Floods on Silver Creek in Ripon, Wis.**

J. O. Shearman and B. K. Holmstrom determined the area that would be inundated by the regional (100-year) flood along a 3.3-mile reach of Silver Creek in the city of Ripon, Wis. The computed regional flood elevation is about 3 to 9 feet higher than normal low-water elevations.

### **Floods on Elk Creek in southwestern Oregon**

The channel capacity and flood characteristics of a reach of Elk Creek from Putnam Valley to Scotts Valley, Oreg., and two tributaries (Pass Creek and Yoncalla Creek) were determined by E. A. Oster.<sup>96</sup> Water-surface profiles of the 2-year and 10-year floods and of the maximum flood of record were determined by the step-backwater method. Corresponding flood boundaries were outlined on a photomosaic map. There is considerable difference in elevation of the three floods, although at places the boundaries may nearly coincide.

### **Flood-inundation maps of urban areas**

Maps showing areas inundated by major floods, flood profiles, discharge-frequency relations, and stage-frequency relations were published during the current year as Hydrologic Investigations Atlases for the following areas: Symerton, Ill. (H. E. Allen Jr., r1646); Paintsville, Ky. (C. H. Hannum, r0259); Salyersville, Ky. (C. H. Hannum, r0840); Morehead, Ky. (C. H. Hannum, r0176); Oneonta, N.Y. (Stephen Hladio, r0776); Hightstown, N.J. (G. M. Farlekas, r0260); Somerset and Mercer Counties, N.J. (T. G. Ross, r1950); Many, La. (A. S. Lowe, r1952); Logtown, Miss. (K. V. Wilson and J. W. Hudson, r0261); English Lookout, Miss. (K. V. Wilson and J. W. Hudson, r0262); Kilm, Miss. (K. V. Wilson and J. W. Hudson, r0263); Waveland and Grand Island Pass, Miss. (K. V. Wilson and J. W. Hudson, r0264); Vidalia, Miss. (K. V. Wilson and J. W. Hudson, r0265);

<sup>96</sup> Oster, E. A., 1971, Floods on selected reaches of Elk Creek, Douglas County, Oregon: U.S. Geol. Survey Hydrol. Inv. Atlas HA-388. [In press]

Bay St. Louis, Miss. (K. V. Wilson and J. W. Hudson, r0266); Gulfport Northwest, Miss. (K. V. Wilson and J. W. Hudson, r0267); Pass Christian, Miss. (K. V. Wilson and J. W. Hudson, r0268); Gulfport North and South, Miss. (K. V. Wilson and J. W. Hudson, r0269); Biloxi, Miss. (K. V. Wilson and J. W. Hudson, r0270); Ocean Springs and Deer Island, Miss. (K. V. Wilson and J. W. Hudson, r2318); Pascagoula, Miss. (K. V. Wilson and J. W. Hudson, r0271); Krole and Grand Bay, Miss. (K. V. Wilson and J. W. Hudson, r2316); Grand Bay, Miss.-Ala. (K. V. Wilson and J. W. Hudson, r0272); Bon Air, Va. (E. M. Miller, r0395); Richmond, Va. (E. M. Miller, r0396); Drewrys Bluff, Va. (E. M. Miller, r0397); and Buena Vista, Va. (G. S. Runner, r0398).

## WATER QUALITY AND CONTAMINATION

The development and use of water in many areas are restricted or complicated by the presence of undesirable waste products and natural constituents in surface and ground waters. To study these undesirable water contaminants, the U.S. Geological Survey conducts basic research and areal investigations that define the causes and the extent of contamination in the natural environment.

### Pesticides in Pennsylvania

Four selected streams, draining areas of different land use (forested, general farming, orchard, and suburban) are being sampled for pesticides in a study by J. F. Truhlar, Jr., and L. A. Reed. Samples are collected during the various seasons and under various flow conditions and analyzed for eight chlorinated-hydrocarbon insecticides and three phenoxy-acid herbicides. The analyses indicate that DDT concentrations do not exceed 0.01  $\mu\text{g/l}$  in any of the streams during low flow.

The maximum observed concentration of DDT (2.5  $\mu\text{g/l}$ ) was in the orchard-area stream during a storm runoff event. Streambed sediments contained about 50  $\mu\text{g/kg}$  of DDT. The study also showed that the suburban stream carried higher concentrations of pesticides than the general farming area, and that the stream in the forested area contained the least pesticides.

### Brine contamination of Montgomery County, Kans.

A study by H. G. O'Connor (Kansas Geological Survey) found extensive ground-water contamination by oil- and gas-field brines in Montgomery County, Kans. The two sandstone aquifers affected occur at

the surface or in the shallow subsurface over approximately half the county.

Present day oil and gas operations are regulated so that brines are safely disposed of without contamination. The 7,000 wells drilled between 1881 and 1934, however, included many that were not properly cased or plugged upon abandonment. During this period the brines produced commonly were released on the land surface or to the nearest stream. Some of the old drill holes locally continue to seep brines into the shallow aquifers.

### Water-quality changes in Florida canals

A study of the highly controlled canal network in Broward County, Fla., by C. B. Sherwood, H. J. McCoy, and Jack Hardee, indicated increasing degradation of water quality. The quality of canal water is important because the canals are cut into the highly permeable limestones of the Biscayne aquifer and provide much of the replenishment of coastal well fields. The chief contaminants are derived from sewage plant effluent, agricultural pesticides, and untreated wastes from boats.

Diurnal dissolved-oxygen studies indicated that during dry periods, when control gates are closed and there is little or no flow, the dissolved-oxygen content in canal waters is reduced to levels lower than those necessary to sustain many forms of aquatic life. The lowest dissolved-oxygen content (0.2 mg/l) occurred in the New River Canal, which receives the most treated effluent (6 mgd).

Traces of pesticides were found in most canals, with the highest level (1.0 mg/l Silvex) occurring in the canal receiving the most effluent. The pesticide level in sediments at the same site was 760  $\mu\text{g/kg}$  DDD.

### Chloride contamination of ground-water supplies near Fort Myers, Fla.

Upward leakage of highly mineralized water from artesian aquifers occurring at depths greater than 1,500 feet, has caused serious contamination of the principal sources of ground-water supply in an area near Fort Myers, Fla. Studies conducted by C. R. Sproul and H. J. Woodward (Florida Bureau of Geology), and D. H. Boggess (U.S. Geological Survey) show that the intruding water, with chloride content of about 19,000 mg/l, has resulted in increased chloride concentrations ranging from about 1,000 to 15,000 mg/l in water from the lower Hawthorne aquifer. In turn, upward leakage from this aquifer has resulted in contamination of the upper Hawthorne aquifer, where chloride concentrations of more than 3,000 mg/l have

been determined. Other shallower water-bearing formations have been similarly affected.

The problem is largely related to well construction methods, whereby two or more aquifers are connected in the open-well bore, although upward leakage along a fault or fracture zone may be the initial process involved.

#### **Fungicide degradation by soil organisms**

A study of the biodegradation of the fungicide dodecylguanidine acetate (dodine) by M. C. Goldberg and R. L. Wershaw (r2326) showed that two soil organisms, a *Flavobacterium* sp. and an *Achromobacter* sp., utilize the materials as the sole source of carbon. By use of C<sup>14</sup>-labeled fungicide, the investigators showed that the biological content of river muds typical of the Denver, Colo., area could degrade up to 5 percent of a dodine charge within 68 days. Preconditioning the river muds to the fungicide neither enhanced nor decreased the amount of biodegradation.

#### **Nitrate contamination of Nassau County, N.Y.**

Contamination of ground water in the upper glacial aquifer by nitrate and other constituents of sewage and fertilizer origin is widespread both in sewered and unsewered areas in southern Nassau County, according to a study by N. M. Perlmutter and Ellis Koch (p. C189-C192). In some places the ground water contains from 45 to 100 mg/l of nitrate. Significant upward trends in nitrate concentration were noted in results of analyses of samples from many deep wells screened in the underlying aquifer in the Magothy Formation, the principal source of water for public supply.

Effluent streams fed by outflow from the upper glacial aquifer also contain a substantial amount of dissolved contaminants compared with streams in undeveloped parts of nearby Suffolk County.

#### **Temperature dependence of the reaeration coefficient**

R. E. Rathbun and J. P. Bennett (r0454) reported that on the basis of the film-penetration model equations, the temperature coefficients for the reaeration coefficient as predicted by the film and penetration models of gas absorption could be calculated from a knowledge only of the temperature dependences of the kinematic viscosity of water and of the molecular diffusivity of oxygen in water. With one exception, all previously reported experimental values of the temperature coefficients fall between the calculated values for the film and penetration models.

## **DISTRIBUTION OF MINOR ELEMENTS AS RELATED TO PUBLIC HEALTH**

### **Geochemical environment in health and disease**

There is a growing awareness among geochemists and biomedical scientists of the need for a strong sustained interdisciplinary effort to clarify the important relationships between geochemical environment and health and disease.

Conferences and symposia in which U.S. Geological Survey personnel were actively involved led to two important broad conclusions: (1) trace elements play an important part in animal and human nutrition and in many physiological reactions; and (2) the prevalence of many diseases has geographic patterns of distribution that appear to be related, in some way, to the geochemical environment.

Geochemists who have been studying the distribution of elements in rocks, soils, plants, and water, particularly in prospecting for ore deposits, have become aware of areal differences of considerable magnitude in both the total metals and available metals that occur naturally in different geologic environments, and in the increments of inorganic substances that can be expected in mineralized areas and in areas contaminated by various types of inorganic pollution.

Scientists from several disciplines have agreed that an interdisciplinary effort should be made to investigate what is known about the distribution of elements in the environment and their availability to plants, animals, and man; to consider ways and means of standardizing data collection and analysis, as well as computer storage and retrieval; to establish avenues of communication and ways of disseminating information among these interdisciplinary groups; and to promote interdisciplinary and international education in regard to the geochemical environment and its effect on health and disease through additional interdisciplinary symposia. Eventually it should be possible to identify, on a statistically sound basis, those correlations between geochemical patterns and disease patterns that do, in fact, exist. A subcommittee led by H. L. Cannon was established within the U.S. National Committee on Geochemistry to further these objectives. Several specific projects related to health are under study by the U.S. Geological Survey.

### **Geochemical survey in Missouri**

A geochemical survey of the rocks, soils, and vegetation of Missouri was commenced during 1969 in cooperation with the Environmental Health Surveillance and Research Center of the University of Missouri. The

Environmental Health Surveillance and Research Center is making a study of the occurrence and distribution of congenital malformations in animals and man in the State of Missouri.

An efficient sampling plan must be developed to accommodate the great diversity of materials distributed over nearly 70,000 sq mi but at the same time conform to manageable cost levels. Preliminary samples were collected throughout the State according to a hierarchical analysis of variance design by R. R. Tidball, soil scientist, to test three levels of the soil classification system currently in use. Taxonomic units within two of the three levels exhibit significant variation individually for numerous elements, but these units tend to overlap when viewed on a multivariate basis. Alternate sampling plans may provide a more effective basis for condensation. Preliminary sampling by J. J. Connor, J. D. Sims, and R. J. Ebens, geologists, of rock in roadcut exposures shows that no effects of vehicular traffic can be demonstrated if hand specimens are trimmed in a conventional manner. Samples of grass collected at the same localities as the test specimens, contain concentrations of lead near roadsides nearly three times that of grass collected away from roadsides.

H. T. Shacklette, J. A. Erdman, and J. R. Keith, botanists, began a study of the biogeochemistry of the vegetation in Missouri. A preliminary investigation of inorganic roadside contamination of vegetation was made by sampling 16 matched pairs of cedar trees across the southern part of the State. Those collected along roadsides contained significantly more lead than those 300 feet from the pavement. Cedars at 3 of the roadside sites contained highly anomalous amounts of lead; as much as 2 percent lead was found in the ash of the tree from one collection site. A more intensive study of the areas of high lead values supported earlier findings, although the site of highest lead and zinc values is believed to have been contaminated by dust of ore concentrate from ore trucks rather than vehicular emissions. Of 28 other elements also measured in cedar and soil samples, chromium was the only other roadside contaminant detected in plant material and no effects of contamination could be detected in soils from the cedar sites. These findings, coupled with those of Connor, Sims, and Ebens, indicate that vegetation near roads cannot be used in studies of the biogeochemical properties of natural plant communities.

#### **Geochemical character of counties in the United States having extreme rates of death due to heart disease**

H. T. Shacklette and J. J. Connor have undertaken a study, in cooperation with the U.S. Public Health

Service (USPHS), directed at pairs of adjacent, or nearly adjacent, counties throughout the United States that have extremely contrasting rates of death due to cardiovascular causes. The pairs of counties are being selected by H. I. Sauer, health statistician, USPHS. The objective of the study will be to search for and define geochemical similarities among counties having high death rates, and to identify any consistent geochemical differences between adjacent counties with contrasting death rates. The study is an extension of a recently completed study in Georgia (Shacklette, Sauer, and Miesch, r0425).

#### **Trace-element excesses and deficiencies in geological provinces of the United States**

Possible excesses and deficiencies of trace metals in different geochemical provinces of the United States were pointed out by H. L. Cannon at the Third Trace Element Symposium at the University of Missouri, and a report was subsequently published (H. L. Cannon, r1873). A characteristic geochemical environment is commonly associated with substrata of a particular rock type. Thus, the elemental content of local soils and plants is affected by unusual amounts of P and K in limestone, Ni and Cu in serpentine, V and U in phosphate rock, Se in shales containing volcanic ash, Li and B in evaporite basins, and by deficiencies of many elements in coastal plain sands. Localized concentrations of metals may occur within these geochemical provinces. Vegetation in these areas has been reported to contain anomalous amounts of many metals. An interdisciplinary team approach to a study of the distribution of trace metals and their availability to plants, animals, and man might provide valuable evidence regarding their effect in the natural environment on health and disease.

### **LAND SUBSIDENCE**

Studies of land subsidence caused by decrease of artesian head in confined aquifer systems are expanding in the United States and abroad because the intensive exploitation of ground-water reservoirs is creating serious subsidence problems. In September 1969, participants from 15 countries gave 68 papers at the first International Symposium on Land Subsidence, held in Tokyo, Japan. The proceedings of this excellent symposium were published in 1970. It was most fitting that the first international symposium was held in Japan because, considering its size, Japan has experienced far more serious subsidence problems than any other country. For example, in Tokyo 40 km<sup>2</sup> of land containing half a million people has sunk as much as



2.3 m below mean sea level as a result of a 35-m decline in ground-water level; and in Osaka, 30 km<sup>2</sup> containing one-third of a million people is now below mean sea level. All internal drainage and flood waters reaching these areas must be pumped out, requiring pumping plants, dikes, and watergates.

#### **Subsidence in south-central Arizona**

Land subsidence in Pinal and Maricopa Counties, Ariz., is related to large-scale ground-water withdrawal and resultant water-level declines, according to H. H. Schumann. Preliminary findings of studies by the Interagency Committee on Land Subsidence in Arizona are as follows:

Large-scale pumping for irrigation has lowered water levels more than 200 feet in central Pinal County, where more than 7.5 feet of subsidence was recorded from 1948 to 1967 near the town of Eloy. Near Stanfield in western Pinal County, pumping has lowered water levels more than 320 feet, and more than 3.5 feet of subsidence occurred between 1948 and 1964.

In Maricopa County from 1948 to 1967, the land surface subsided 3.8 feet near Queen Creek, where pumping has lowered water levels more than 200 feet, and 3.7 feet about 7 miles east of the city of Mesa, where the water level has declined more than 340 feet. West of Luke Air Force Base, the maximum documented subsidence from 1948 to 1967 was 2.1 feet.

Land subsidence and associated earth fissures have damaged irrigation systems, water wells, farmlands, interstate highways, and railroads, and have necessitated the rerouting of a proposed major aqueduct.

#### **Subsidence in west-central San Joaquin Valley, Calif., now 28 feet**

Comparison of U.S. Coast and Geodetic Survey adjusted leveling data of February 1969 with that of March 1966 in the Los Banos-Kettleman City area indicated that maximum subsidence was 2.7 feet, or 0.9 foot per year. In most of this area of 1,500 sq mi, subsidence in the 3 years ranged from 0.5 to 2.0 feet, and was continuing at about the same rate as that between 1963 and 1966. In much of the central reach of most rapid subsidence, traversed by the San Luis Canal-California Aqueduct, the 3-year amount had decreased 0.5 to 1.0 foot from that of 1963-66. Maximum historic subsidence since the 1920's has occurred 10 miles southwest of Mendota; by 1969 the subsidence had reached 28 feet. At that site, however, J. F. Poland (r2577) found that subsidence has decreased from 1.76 feet per year in 1953-55 to 0.67 foot per year in 1966-69.

#### **Subsidence continues in only part of the Tulare-Wasco area, California**

Releveling of the Tulare-Wasco subsidence network in early 1970, last surveyed in 1962, showed a marked contrast between areas receiving canal irrigation supply and those areas supplied by ground water from local wells, according to B. E. Lofgren. Less than 0.5 foot of subsidence occurred during this 8-year period in much of the Friant-Kern Canal service area. Subsidence continues unabated in the heavily pumped western half of the area. Subsidence exceeded 3 feet in a broad area southwest of Pixley, west of Hanford, and southwest of Alpaugh. Compaction of deposits to a depth of 760 feet accounted for about 60 percent of the 2.5 feet of subsidence between 1962 and 1970 at the multiple-recorder site 3 miles south of Pixley. Compaction below 760 feet has increased to 40 percent of the subsidence from an earlier 25 percent, apparently in response to increased pumping of deeper wells.

#### **Subsidence in the Arvin-Maricopa area, California**

B. E. Lofgren completed a subsidence study of the Arvin-Maricopa area south of Bakersfield, Calif., where about 450 sq mi of irrigable land is subsiding and, locally, rates exceed 0.5 foot per year. Although hydrocompaction, oil-field extractions, and tectonic adjustment all contributed to the subsidence, most was caused by the pumping overdraft of the ground-water reservoir. The volume of subsidence to 1965 exceeded 800,000 acre-ft.

Releveling of bench marks in early 1970 indicates that subsidence continues throughout most of the area. The pumping of deeper irrigation wells in much of the area, however, has caused compaction rates in the intermediate zones to diminish and compaction rates in the deep zones to increase.

It was concluded that much of the overdraft of the ground-water basin is due to precipitation deficiencies since 1946. Normal precipitation and the importation of surface water should cause an abrupt decrease in subsidence rates.

#### **Subsidence rate decreasing in Santa Clara Valley, Calif.**

Importation of surface water from the Central Valley to the Santa Clara Valley through the State's South Bay Aqueduct, since 1966, plus increased local supply from precipitation and runoff into detention reservoirs, has reduced ground-water pumpage and increased recharge, causing artesian heads to rise several tens of feet since 1967. J. F. Poland reported that releveling of bench marks in San Jose by the U.S. Coast and Geodetic Survey revealed a marked decrease of sub-

sidence rate as a result of the rise in artesian head. For example, at bench mark P7, the rate of subsidence from October 1960 to February 1963 was 0.72 foot per year (the maximum historic rate), but from 1963 to January 1967 the rate decreased to 0.40 foot per year, and from 1967 to March 1969 was only 0.10 foot a year, the lowest rate since the middle 1940's. Records from compaction recorders indicate that the reduction is widespread and that rebound of the land surface locally exceeded 0.1 foot during the winter head recoveries of 1968-69 and 1969-70.

**Compressibility of an aquifer system determined from in situ measurements**

A major difficulty in attempting to analyze and predict subsidence due to artesian-head decline is the determination of the compressibility of the compacting aquifer system. The hydrodynamic time lag associated with the slow expulsion of water from low-permeability sediments characteristically causes the apparent compressibility (strain-stress ratio) at any intermediate time during the compaction process to be much less than the true value of compressibility at "ultimate" time. F. S. Riley found that a continuous stress-strain plot derived from several years of compaction and head-change data provides a particularly versatile and instructive interpretive tool that in-

cludes among its uses a means of estimating true compressibility.

In areas of strongly seasonal ground-water pumpage, the annual cycles of head decline and recovery generate a stress-strain diagram consisting of a series of open loops which clearly define gross compaction, elastic expansion, and net permanent compaction of the confined aquifer system. The gradually increasing value of the average preconsolidation stress, the elastic compressibility of the aquifer system at lesser stresses, and the much larger inelastic compressibility at greater stresses can often be determined from such diagrams. At a given location, these compressibilities may differ by as much as two orders of magnitude. Under favorable circumstances, fairly consistent values of the hydrodynamic time constant for the compaction process have been obtained for nine successive annual cycles. Given a value for the aquifer-system time constant and knowledge of the number and thickness of compacting aquitards (semiconfining strata), it is possible to calculate the hydraulic and mechanical properties and the thickness of a "characteristic" aquitard. The response of this hypothetical bed to changes in head can be calculated from the consolidation theory of soil mechanics. Such response, multiplied by the number of aquitards, approximates the behavior of the real compacting aquifer system.

## ASTROGEOLOGY

### LUNAR EXPLORATION

In 1969, years of preparation by the Apollo lunar geology team in support of the National Aeronautics and Space Administration (NASA) program for lunar surface exploration bore fruit in the landings of Apollo 11 in Mare Tranquillitatis, and of Apollo 12 near Surveyor 3 in Oceanus Procellarum. These missions provided, for the first time, reliable information on stratigraphy, composition, and texture of near-surface lunar rocks, on absolute ages of lunar materials, and on lunar surface processes.

Research and development activities in support of manned lunar exploration missions have resulted in significant contributions to the geology and geophysics of the San Francisco volcanic field in northern Arizona, to knowledge of lunar surface characteristics, and to the analysis and definition of effective techniques and procedures for carrying out geologic field investigations.

#### Apollo lunar geology experiment

The regolith at the Apollo 11 landing site is a layer of fragmental debris that ranges in thickness from about 3 to 6 m, according to E. M. Shoemaker and others<sup>97</sup> (r0553). The thickness of the regolith and the exposure histories of its constituent fragments can be related, by means of a relatively simple model, to the observed crater distribution. About 5 percent of the material composing the regolith at Tranquillity Base is expected to have come from the highland regions of the Moon. Anomalous calculated ages of the regolith material are probably to be explained by contamination of the regolith with small amounts of highland material, rich in radiogenic lead and strontium, as reported by H. H. Schmitt<sup>98</sup> and G. E. Lofgren (NASA), Gene Simmons (Massachusetts Institute of Technology), and G. A. Swann and Shoemaker<sup>99</sup> (USGS).

<sup>97</sup> Shoemaker, E. M., and others, 1970. Origin of the lunar regolith at Tranquillity Base: Apollo 11 Lunar Science Conf., Proc., *Geochim. et Cosmochim. Acta*, Supp. 1, v. 3, p. 2399-2412.

<sup>98</sup> Schmitt, H. H., Lofgren, Gary, Swann, G. A., and Simmons, Gene, 1970. The Apollo 11 samples—Introduction: Apollo 11 Lunar Science Conf., Proc., *Geochim. et Cosmochim. Acta*, Supp. 1, v. 1, p. 1-54.

<sup>99</sup> Shoemaker, E. M., and others, 1969. Geologic setting of the lunar samples returned by the Apollo 11 mission: NASA SP-214, p. 41-83.

The regolith at the Apollo 12 landing site is estimated by Shoemaker and others<sup>100</sup> to be from less than a meter to 2 m thick. Several of the returned samples can be tentatively correlated with their bedrock sources. Three types of patterned ground were reported by the crew: (1) that which comprises small north- and east-trending grooves, which may reflect underlying bedrock structures; (2) that which is similar in appearance to "raindrop patterns" in soft materials, which may be caused by recent showers of secondary particles from meteoritic impact, and (3) concentrically terraced slopes in some craters, that may be caused by down-slope creep in crater walls.

#### Test-site mapping and analog studies

Mapping by E. W. Wolfe and R. B. Moore in the San Francisco volcanic field, north-central Arizona, has revealed a complex sequence of alkali olivine basalt and olivine tholeiite lava flows, and pyroclastic and alluvial deposits of latest Tertiary(?) and Quaternary age. So far, eight separate deposits of sandy palagonitic(?) tuff have been found. These occur as low tuff rings about a kilometer in diameter, as portions of broad cinder cones, and in one case, as part of a linear ridge that probably represents a fissure vent. Gravity data on one tuff ring show a 2-mgal negative anomaly. The tuff may have resulted from steam explosion when rising basaltic lava encountered water-saturated Cocomino Sandstone.

#### Mission development and support

Magnetometer data, continuously transmitted from a traversing vehicle, were used successfully by geologists and geophysicists to define and delineate basalt flow-sedimentary rock contacts buried by alluvium and pyroclastic deposits in the eastern part of the San Francisco volcanic field near Flagstaff, Ariz. The data were reduced and interpreted in real time together with observational data transmitted from the vehicle by radio during a 3-day reconnaissance that simulated some aspects of lunar geologic exploration by roving vehicle.

Measurements of lunar surface characteristics permit terrain analysis at various scales utilizing high- and

<sup>100</sup> Shoemaker, E. M., and others, 1970. Preliminary geologic investigation of the Apollo 12 landing site: NASA Special Publication [In press]

low-altitude Lunar Orbiter photography, Surveyor photography, and Apollo orbital and surface photography to provide a basis for extrapolation of terrain models down to the working level of an astronaut or a wheeled vehicle (see work reported by W. J. Rozema, r0326, for part of this study). The characteristics for a wide range of lunar terrain models, including surface roughness (power spectral density), slope, and crater and block frequency distributions have been integrated into hypothetical reference traverses for both local manned vehicle missions and long-range automated missions. Extrapolation of the statistical data permits estimates of the increase in ground distance over map distance due to these characteristics for each of the terrain models. The data thus accumulated over a representative lunar traverse provide a basis for engineering analysis of a vehicle's capability to perform a given mission.

Traverse maps prepared in consultation with the crew of Apollo 12 were completed by the U.S. Geological Survey for incorporation in the Apollo 12 data package. These traverse maps were used by the astronauts on the lunar surface during the mission and contributed significantly to the success of the geologic investigations.

By use of buried explosive charges, a crater field was constructed on Black Mesa in the Verde Valley in central Arizona for mission training of the Apollo 13 crew. The field also provided an opportunity for carrying out joint experiments in (1) engineering seismology, (2) crater mechanics, and (3) crater geology. Preliminary evaluation of the data promises significant results in all three areas of investigation. The exercise carried out by the Apollo 13 astronauts under the time constraints of lunar missions produced data which compare satisfactorily with the logs of the shotholes and provided the essential petrographic and stratigraphic relations of the near-surface rock units. Preliminary studies by Geological Survey geologists indicate that more detailed study of crater-ejecta patterns, requiring considerably longer periods of time, will yield finer detail on stratigraphy and facies relations that will compare favorably with results from detailed logs of shotholes.

#### **Research in geologic methods**

A mobile laboratory designed for analytical support in the field while field investigations are in progress will permit between 10 and 15 rapid rock analyses per day, plus some additional trace-element determinations. These chemical analyses are obtained by the use of an atomic absorption unit and an ultraviolet-visible spectrophotometer. Mineralogy of the rock is determined with a miniature X-ray diffractometer and a

petrographic microscope. This equipment plus a small semiautomated thin-section machine is transported in a camper box mounted on a four-wheel drive pickup truck. The rapid chemical and petrographic support offered by this laboratory is of valuable service in distinguishing and correlating rock units.

A vehicle-mounted magnetometer system was tested in an area in central Arizona that displays a variety of intrusive and extrusive features in a small basaltic complex. The system includes a gyro-operated, total-field magnetometer that remains oriented in a north-south plane and mounted on a vehicle so that the sensing head is 20 feet above the ground surface. The character of the magnetic field was read out as a continuous plot on a digital display while traversing a variety of exposed features. The features include the interface between several superimposed flows, interfaces between flows and cinder deposits, dikes cutting flows, dikes cutting cinder deposits, surfaces of flows, and surfaces of thick deposits of cinders. A comparison of anomalies over exposed features with anomalies over buried terrane permitted identification and location of features under as much as several feet of soil and alluvial cover.

## **LUNAR AND PLANETARY INVESTIGATIONS**

### **Multiringed lunar basins**

Continuing studies of Lunar Orbiter IV photographs aided stratigraphic and genetic interpretations of the Moon's large circular multiringed basins. D. E. Wilhelms reported that these basins play the dominant role in controlling the stratigraphy and structure of the Moon as well as shaping its topography. They are analogous in importance to the global-scale plates and orogenic belts on Earth. A stratigraphically important result of recent regional studies is the identification of swarms of craters in the southern highlands as secondary impact craters of the Imbrium Basin. This interpretation is based on the apparent age equivalence of the craters (estimated from age and density of superposed and subjacent craters) and the Imbrium Basin, and on striking similarities in their morphology and clustering habits with other secondary impact craters. Some of the Imbrium secondary clusters, the largest of which extend some 300 km across the lunar surface, are in the form of loops convex outward from the Imbrium Basin and resemble in plan the loops of secondary craters around the smaller crater Copernicus. In a given cluster, the smallest individual craters and certain radial scours are densely packed on the side farthest from the basin. Many individual craters of

the clusters have an irregular plan shape, and almost all have a bowl-shaped profile—characteristics of craters formed by relatively low-velocity secondary impact. The size of the craters, as much as 25 km in diameter, is about that expected by extrapolation from the more readily recognizable secondaries around the smaller Orientale Basin. The distance at which they occur from the basin,  $1\frac{1}{2}$  to 3 basin diameters, is compatible with that observed around Orientale and smaller craters when scaling factors are considered. The discovery of these Imbrium secondary craters greatly assists in separating pre-Imbrian from Imbrian deposits over a large area of the Moon. Many of these Imbrium secondary craters were formerly thought to be of volcanic origin because of their shape and arrangement in loops and clusters.

Another discovery that will greatly aid in establishing the relative age of lunar rocks is the recognition of an extensive unit around the pre-Imbrian Nectaris Basin. The newly discovered unit appears to be a degraded blanket of material ejected from the Nectaris Basin. Like the two Imbrian-age blankets around the Orientale and Imbrium Basins, the unit can be used to separate prebasin and postbasin deposits over a wide area, but this is the first such subdivision among rocks entirely of pre-Imbrian age.

Additional comparisons among basins led to a new understanding of the spacing between the multiple rings that surround each basin. By careful plotting it was found that the distance between successive rings increases progressively outward from the basin by a factor approximating the square root of two. Knowledge of this spacing helped in the discovery of several previously unrecognized, very ancient circular multi-ringed basins. One of these apparently determines the distribution of much of the mare material in the southern part of the otherwise irregular Oceanus Procellarum. Mapping of all known rings clearly shows that basin structures are the major controlling factor in determining lunar physiography and the location of most volcanic deposits both of the maria and the terrae.

#### **Apollo site mapping**

Prior to the Apollo 12 mission to the Moon, geologic maps of the landing site were prepared by H. A. Pohn and P. J. Cannon at scales of 1:25,000 and 1:250,000. Mare material in the site was shown as younger than that in the Apollo 11 landing site 1,500 km to the east—a result that appears to have been confirmed by preliminary radiometric dating of the samples. A south-trending ray from the crater Copernicus, many kilometers to the northeast, was shown on the maps. The coarse-grained mafic and ultramafic

rocks with cumulus textures among the returned lunar samples may be deep-seated rocks ejected from Copernicus. Alternatively, they might be projectiles from another source which formed the younger secondary crater clusters mapped in the vicinity of the landing site.

#### **Radar mapping**

While investigating the applicability of radar imagery to the geologic study of the planets, especially those obscured by a dense atmosphere, G. G. Schaber and R. E. Eggleton found that radar imagery could be used to supplement conventional mapping techniques in mapping the lunar surface. Study of 70-cm (430 MHz) Earth-based radar data (obtained from the Arecibo Ionospheric Observatory, Puerto Rico) of the Sinus Iridum quadrangle showed an excellent correlation between mare materials of different ages and the intensity of radar backscatter. Within areas known to be occupied by mare material, the lowest radar reflectivity values define the youngest units, which are otherwise characterized by low albedo, "blue" spectral reflectivity, and low density of superposed craters. Higher values define older mare units having a higher albedo, a "red" spectral response, and a greater density of craters.

#### **Lunar and planetary geodesy**

Lunar Orbiter and Apollo photographs proved to be suitable for relatively precise determination of lunar surface positions and for determining the configuration of the Moon. An analytical technique developed by D. W. G. Arthur to obtain positional data for cartographic control is now being extended onto the averted lunar hemisphere. It should be equally applicable to Mars and will be tested when suitable pictures from the Mariner Mars 1969 mission become available. The method assumes strict lunar sphericity. In the treatment of coordinate measures (on Apollo 8 pictures) reasonably accordant lunar surface positions are obtained by the use of this assumption. Significantly, results obtained to date imply that the earthward elongation of the Moon, derived from Earth-based selenodesies, may be illusory. This important conclusion will be investigated further.

## **CRATER INVESTIGATIONS**

#### **Explosion craters, Alberta, Canada**

Detonations by United States and Canadian government agencies of 100-ton and 500-ton TNT hemispheres and spheres tangent to an alluvial ground

surface have produced craters whose structural and topographic configurations resemble those of certain large terrestrial and lunar craters of impact origin. D. J. Roddy reports that similarities between the two types of craters include: (1) central uplifts, (2) complexly folded and faulted rims, (3) thin breccia lenses beneath the floor, (4) similar (scaled) distances between concentric zones of rim deformation, (5) stratigraphically inverted rim flap deposits, and (6) outward gradation of the overturned rim flap into a continuous blanket of ejected particulate debris which in turn grades into ray deposits composed largely of discrete ejecta fragments and their associated craters. Fused spherules occur in the debris of the test explosions. In size and general appearance they resemble spherules in the returned samples of lunar material. The terrestrial examples probably resulted from cooling of jets of molten rock material formed during the early stage of the explosion.

#### **Shatter cones in explosion craters, Cedar City, Utah**

Well-developed shatter cones were produced in quartz diorite in several U.S. Department of Defense cratering experiments studied by D. J. Roddy near Cedar City, Utah. The largest crater, 14 m across and 3 m deep, was formed by a 100-ton TNT sphere buried 0.25 m (center 2.2 m above ground); several ejecta blocks exhibited typical conical fracture surfaces of shatter cones with parasitic nests of cone segments up to 0.5 m long. One of the smaller craters, 2.4 m across and 0.33 m deep, was formed by a 1,000-pound TNT sphere buried 0.04 m (center 0.37 m above ground). Striations on a complete shatter cone, 0.3 m across the base and 0.2 m high, and on several cone segments were measured in place on this crater floor. Apical angles are  $90^\circ \pm 5^\circ$ , and shock pressures are estimated to be  $30 \text{ kb} \pm 5 \text{ kb}$  in the area of these cones. Measurements using stereographic projections show that: (1) shatter cones can be produced by shock waves and their interactions with free surfaces, (2) shatter cone apices point in the direction of the originating energy source, and (3) cone axes are normal to the shock-wave front and pass through the center of the originating energy source. These data allow more confident use of shatter cones as criteria for shock-wave deformation and direction of shock-wave propagation at the larger proposed natural impact (cryptoexplosion) sites.

#### **Gosses Bluff impact structure, Australia**

Synthesis of coordinated geologic study, principally by D. J. Milton (U.S. Geological Survey), and geophysical studies (by the Bureau of Mineral Resources

of Australia) have made Gosses Bluff in central Australia perhaps the best known cryptoexplosion structure in the world and a useful analog for the study of lunar craters. Gosses Bluff itself consists of strata uplifted as much as 11,500 feet and tilted from an originally horizontal attitude to the vertical; it represents the central peak of the former crater. Deformed strata that lay beneath the former crater floor and some remnants of highly shocked and partially melted crater-floor fill occur in a circular zone 10 miles in diameter surrounding the bluff. The topographic rim of the crater has been destroyed by erosion, but chaotic structures between 5 and 7 miles from the center of the structure represent remnants of the geologic rim zone. Seismic reflection indicates a bowl-shaped disturbance bottoming at about 18,000 feet. A gravity anomaly of about  $-5 \text{ mgal}$  is associated with the structure as a whole. There is no overall magnetic anomaly, but strong local anomalies are associated with remnant patches of melted and highly shocked breccia which acquired an inverse remanent magnetization when cooling after the cratering event during a reversed magnetic epoch. Potassium-argon dating on sanidine from melt breccia, and fission track dating of annealing of zircon in sandstone underlying melt breccia indicate an Early Cretaceous age. Computer restoration of shatter cones to their position before displacement indicates a focus higher than any exposed strata and close to the ground level in the Cretaceous. The shallow focus virtually eliminates any hypothesis of origin except by impact.

#### **Decaturville explosion structure, Missouri**

The Decaturville cryptoexplosion structure in Missouri consists of a central domal uplift and surrounding structural depression whose outer limit is defined by a circular fault. Thrust faults and folds overturned outward on the fringes of the uplift may have been produced partly by sliding of blocks toward the adjacent depressed zone. In the center of the uplift, large blocks containing shatter cones and probable shock lamellae are displaced hundreds of feet stratigraphically upward or downward and possibly form a megabreccia core of the structure. All the carbonate units are characterized by brecciation which extends to the circular fault delimiting the structure. Dike-like injection breccias containing sulfides postdate the main phase of brecciation. The geometry of the structure, intraformational and interformational deformation, and the presence of probable shock indicators suggest an impact origin for the Decaturville structure. Why the circular Decaturville structure occurs at the inter-

section of three linear subsurface structures of regional extent is still unexplained, however.

#### **Shock effects in calcite related to cratering by impact**

Several different types of planar features reported from different meteorite and "cryptoexplosion" sites have been attributed to the high pressures created by the passage of shock waves. Only a limited amount of experimental data are available, however, to aid in interpreting these features and in determining the pressures under which they formed. Experimental shots generating shock pressures from 5 kb to 30 kb have been fired at calcite crystals. Lattice deformation indicated by X-ray line broadening has been found at pressures as low as 10 kb and becomes increasingly common in all crystal orientations at higher shock pressures. Petrofabric studies by D. J. Roddy indicate a corresponding increase in the number of planar features accompanying the higher shock pressures;  $e$  and  $r$  planar orientations are noticeable, with three sets present at the higher pressures.

The types of deformation in the calcite samples are quite similar to those observed in calcites from the Flynn Creek crater, Tennessee, and other proposed comet impact craters. Crystals and polycrystalline aggregates shocked under these controlled conditions serve as pressure- and temperature-calibrated material for comparison with rock materials that have been shock loaded during a meteorite or comet impact, in both terrestrial and lunar environments. Under appropriate conditions, it should be possible to identify sites created by impact and to establish shock pressure ranges.

### **VOLCANIC INVESTIGATIONS**

#### **Mule Ear diatreme, Utah**

The Mule Ear diatreme in Utah was studied to understand volcanic structural and stratigraphic relations better for astrogeologic mapping and interpretation. The diatreme at its present exposure level contains a mixture of blocks of sedimentary rocks that have been displaced downward (some more than 5,000 feet) and basement-complex xenoliths that have been transported upward. Some of the latter probably have been displaced tens of thousands of feet. As mapped by D. E. Stuart-Alexander, the diatreme is crudely zoned into a thick outer zone of dominantly down-dropped blocks of sedimentary rocks, an irregular middle zone of reconstituted clastic sedimentary materials with minor admixed debris from igneous and metamorphic rocks, and an inner core of uplifted xenoliths and pulverized debris that may be altered

foreign igneous material or altered material related to the diatreme.

The crude zoning of the rocks probably reflects differences in the movement pattern within the diatreme. Stopping seems to have been the primary mechanism of enlarging the diatreme. Active disaggregation or comminution of the sedimentary rocks occurred in the middle zone followed by limited mobilization and injection in the form of sandstone dikes. The strongest deformative forces and greatest distances of transportation took place in the innermost zone.

Limits have been placed by C. W. Naeser on both the age of the diatreme and its temperature during formation, in his fission-track studies of two granitic xenoliths from the diatreme. Apatite was dated from both xenoliths, indicating ages of  $28 \pm 3$  m.y. for the cooling of the diatreme. The single sphene date was  $690 \pm 100$  m.y., showing that only part of its original fission tracks were lost, and placing the maximum heating of that xenolith between  $300^\circ\text{C}$  and  $500^\circ\text{C}$ . Furthermore, this temperature indicates that the granitic xenolith was not immersed directly in a basaltic magma and suggests that the transporting and eruptive material was a mixture of gas and particulate matter.

### **COSMIC CHEMISTRY AND PETROLOGY**

#### **Cosmic dust**

Examination by M. H. Carr of particulate debris left in the upper atmosphere by two large fireballs, Revelstoke (Canada) and Allende (Mexico), led to the recognition of two different types of meteorite events. Large amounts of meteoritic debris from the Revelstoke fireball still remained in the atmosphere even though sampling was done 3 days after the event. The debris consisted of magnetite spheres, silicon spheres, and irregular nickel-rich particles. All were smaller than  $20\mu$  in diameter. Sampling of material from the Allende fireball was completed within 20 hours after the fireball was observed, yet very little meteoritic material was found in the atmosphere despite large amounts found on the ground. The findings confirm previous suspicions, based on observations of meteor trails, that some meteorites such as Revelstoke disintegrate almost completely in the atmosphere, whereas others such as Allende do not.

#### **Accretionary history of the Murray chondrite**

D. P. Elston has divided the characteristic components of the Murray carbonaceous chondrite into (1) a preaccretionary, volatile-rich, low-temperature assem-



blage, (2) a preaccretionary high-temperature assemblage, and (3) an accretionary high-temperature assemblage. Textural and paragenetic relations suggest that the accretion of the meteorite occurred in a dynamic environment marked by the formation of type 3 material. Precipitation of high-temperature magnesium silicate grains followed by injection into a cold environment containing preaccretionary materials is proposed as the mechanism for formation of this carbonaceous chondrite.

#### Water in tektites and other glasses

F. E. Senftle, A. N. Thorpe, and C. C. Alexander determined the water contents of some tektites, impactites, and artificial glass of tektite composition, by infrared analysis. The tektites had an average water content of 0.01 percent. Impact glass and glasses formed in the atmosphere had about three times this amount of water. Detailed studies on tektite thin sections showed a nonuniform distribution and a lower amount of water along what appears to be the aerodynamically heated side of the tektite.

#### The new mineral pecoraite in the Wolf Creek meteorite

The mineral pecoraite ( $\text{Ni}_6\text{Si}_4\text{O}_{10}(\text{OH})_8$ ), the nickel analog of clinochrysotile, was discovered in the Wolf Creek meteorite from Australia by G. T. Faust (r0082). Its discovery establishes the nickel end member in the system  $\text{H}_2\text{O}-\text{NiO}-\text{MgO}-\text{SiO}_2$ . It is unique in that the crystalline units form as curved sheets, coils, and spirals. These units in the meteorite are never large enough to form tubes. Synthetic pecoraite, however, forms as excellent tubes.

## INVESTIGATIONS OF APOLLO LUNAR SAMPLES

#### The petrology of unshocked crystalline rocks

O. B. James and E. D. Jackson found most of the crystalline rock fragments in the sample of lunar regolith returned by Apollo 11 to be ilmenite basalts.<sup>101</sup> The mineralogy of all the rocks is similar; clinopyroxene, calcic plagioclase, and ilmenite, with olivine a common minor constituent. They differ considerably in textures, bulk chemical compositions, sequence of crystallization, and mineral compositions. Two textural variants make up the bulk of the fragments: intersertal basalts (most type A rocks), and ophitic basalts (all type B rocks).

Ophitic basalts may be subdivided into fine- and medium-grained types, and their textures, whole-rock

compositions, mineral proportions, and mineral compositions vary systematically with grain size. The textural variations and compositional trends are similar to those of terrestrial basalts from partly differentiated sills or thick lava flows, and the ophitic basalts are probably derived from one or more thick lunar lava flows or sills that fractionated slightly on cooling.

Intersertal basalts have more uniform whole-rock compositions, mineral proportions, and mineral compositions than do ophitic basalts, and it appears that the samples are derived from the same or closely related magmas that did not fractionate appreciably during crystallization. These rocks have textures indicating that their parent magma was extruded onto the lunar surface and cooled rapidly. Hornfels textures in many samples suggest that they have been thermally metamorphosed, but this process did not greatly modify vesicularity, mineral proportion, whole-rock composition, or mineral composition. Textures of both primary volcanic and annealed basalts are identical with those of basalts from terrestrial lava lakes, and it seems likely that the intersertal basalts crystallized in one or more lunar lava lakes.

R. L. Tuthill and Motoaki Sato investigated the phase relations of a simulated basalt of the composition of Apollo 11 rocks under varying oxygen fugacity at 1 atm total pressure. Oxygen fugacities between the values for the magnetite-wüstite and the quartz-fayalite-iron buffers had little effect on the crystallization temperatures of the minerals. The sequence of crystallization: ferropseudobrookite (1,210°C), olivine (1,200°C), ilmenite and plagioclase (1,140°C), and pyroxene (1,113°C), agreed well with the observed textures of the Apollo 11 rocks.

E. W. Roedder and P. W. Weiblen found that silicate immiscibility, a petrologic process long suspected but never proved to have been active in the origin of certain earth rocks, has occurred on the Moon.<sup>102</sup> During the later stages of crystallization of the Apollo 11 rocks, the remaining residual fluid finally reached a composition which could not exist as a single fluid, and hence separated into two immiscible fluids, like oil and water. These two melts have chemical compositions approximating potassic granite and pyroxenite.

#### Mineralogy of lunar crystalline rocks

Malcolm Ross, A. E. Bence, E. J. Dwornik, J. R. Clark, and J. J. Papike studied the clinopyroxenes

<sup>101</sup> James, O. B., and Jackson, E. D., 1970, Petrology of the Apollo 11 ilmenite basalts: *Jour. Geophys. Research*. [In press]

<sup>102</sup> Roedder, E. W., and Weiblen, P. W., 1970, Lunar petrology of silicate melt inclusions, Apollo 11 rocks: *Apollo 11 Lunar Science Conf., Proc., Geochim. et Cosmochim. Acta, Supp. 1, v. 1, p. 801-837*.

from the lunar samples. Single-crystal X-ray diffraction, microprobe, optical, and electron optical examinations of clinopyroxenes from Apollo 11 lunar samples 10003, 10047, 10050, and 10084 show that generally the crystals are composed of (001) augite-pigeonite intergrowths in varying ratios. Transmission electron micrographs reveal abundant exsolution lamellae, many only 60 Å thick. In addition to the phase inhomogeneities, primary chemical inhomogeneities are clearly demonstrated. There are reciprocal relationships between calcium and iron and between  $Ti^{4+} + 2 Al$  and  $R^{2+} + 2 Si$ . In the samples studied, the evidence suggests that a chemically inhomogeneous subcalcic C2/C augite was the only primary pyroxene from which pigeonite later exsolved.

Plagioclases from Apollo 11 crystalline rocks were investigated by D. B. Stewart, D. E. Appleman, J. S. Huebner, and J. R. Clark. Bytownite from eight crystalline lunar rocks did not differ in any obvious ways from terrestrial bytownite of the same composition. Type B lunar rocks contain bytownite 5 to 10 percent by weight more calcic than type A rocks, and the measured crystallographic details suggest that these two rock types represent different units rather than being varieties of a single unit. The bytownite in both units has relatively high Al/Si disorder.

The only sulfide phase, troilite, present in Apollo 11 crystalline rocks was investigated by H. T. Evans, Jr. Unusually fine, single crystals made possible a full-scale, three-dimensional, crystal-structure analysis, and the previously proposed structure was confirmed and refined to a high degree of accuracy.

#### Age determination and isotopic studies

An isotopic study of uranium-thorium-lead systematics was made by Mitsunobu Tatsumoto on the Apollo 11 lunar samples. Concentrations of uranium, thorium, and lead in Apollo 11 samples studied are low (U, 0.16–0.87 ppm; Th, 0.53–3.4 ppm; Pb, 0.29–1.7 ppm), but the lead is extremely radiogenic.

Interpretation of the uranium-lead evolution diagram reveals that the initial age of the moon is 4.60 to 4.63 b.y. and that the crystalline rocks at Tranquillity Base are 3.4 to 3.8 b.y. old. The initial age is comparable with the age of the earth and meteorites and suggests a formation at the beginning stage of the solar system rather than a later derivation from the earth.

Oxygen isotope ratios of the Apollo 11 lunar rocks ( $\delta O^{18} = 5.7$  to  $6.3$ ), measured by J. R. O'Neil and L. H. Adami, are within the range found for unaltered terrestrial basalts. Basaltic achondrites and mesosiderites do not appear to be genetically related

to lunar material on the basis of the oxygen isotope ratios of their pyroxenes. From the oxygen isotope fractionation between plagioclase and ilmenite, the temperature of crystallization of type B rocks is estimated to be 1,100° to 1,300°C, in agreement with the melting experiments of R. L. Tuthill and Motoaki Sato.<sup>103</sup>

Irving Friedman, O'Neil, Adami, J. D. Gleason, and K. G. Hardcastle analyzed the Apollo 11 lunar samples for  $H_2O$ , D/H,  $C^{13}$ , and  $He^4$ . The breccia samples contain approximately 150 ppm  $H_2O$  and 50 ppm free hydrogen, both depleted in deuterium by factors of 3 to 6 over terrestrial materials. Some or all of the water may be generated on the moon by reactions of solar wind protons with oxygen in silicates and oxides: approximately 200 ppm of carbon was found, about half in the form of  $CO_2$ , and the remainder as either carbides or elemental carbon. The total  $\delta C^{13}$  is approximately  $-15$  per mil PDB<sup>104</sup> which is well within the terrestrial range. Helium is very abundant in the breccia ( $\approx 0.1$  cm<sup>2</sup>/g) and has a  $He^4$  to  $He^2$  ratio of 2,000 to 4,000.

#### Chemical analyses of lunar materials

Using classical methods, L. C. Peck and V. C. Smith analyzed three lunar samples: an ophitic ilmenite basalt, an intersertal ilmenite basalt, and a sample of lunar fines. The lunar rocks were unusually high in titanium content compared with terrestrial basaltic rocks.

Seven whole-rock fragments, five portions of pulverized lunar rock, and a lunar soil sample were analyzed by semimicro chemical and X-ray fluorescence methods by H. J. Rose, Jr., Frank Cuttitta, E. J. Dwornik, M. K. Carron, R. P. Christian, J. R. Lindsay, D. T. Ligon, Jr., and R. R. Larson (r0551). Three different rock types were represented: vesicular fine-grained basalt, fine- to medium-grained ophitic crystalline rocks, and breccia. The ranges (in weight percent) for the major constituents of the lunar samples are:  $SiO_2$ , 38 to 42;  $Al_2O_3$ , 8 to 14; total iron as FeO, 15 to 20; MgO, 6 to 8; CaO, 10 to 12;  $Na_2O$ , 0.5 to 1;  $K_2O$ , 0.05 to 0.4;  $TiO_2$ , 8 to 13; MnO, 0.2 to 0.3; and  $Cr_2O_3$ , 0.2 to 0.4. Selected minor elements were also determined.

Thirteen lunar samples of igneous rocks, breccias, and fines were analyzed for minor-element concentrations by C. S. Ansell and A. W. Helz (r0545) using d-c arc emission spectroscopy. Zn, Cu, Ga, Rb, Li,

<sup>103</sup> Tuthill, R. L. and Sato, Motoaki, 1970, Phase relations of a simulated lunar basalt as a function of oxygen fugacity, and their bearing on the petrogenesis of the Apollo 11 basalts: *Geochim. et Cosmochim. Acta*. [In press]

<sup>104</sup> PDB, Pee Dee Belemnite standard.

Mn, Cr, Co, Ni, Ba, Sr, V, Be, Nb, Sc, La, Y and Zr were determined. The breccias had higher concentrations of Ni, Zn, and Cu than did the igneous rocks. Concentrations of Rb, Li, Sc, La, Y, and Ba tend to be higher in the igneous rocks.

#### Physical properties of lunar rocks

R. R. Doell, C. S. Grommé, A. N. Thorpe, and F. E. Senftle<sup>105</sup> (r0544) measured the magnetic properties of lunar samples. They found that the remanent magnetism of a lunar breccia includes a large viscous component with a time constant of several hours and a high coercivity remanence. It is suggested that this remanent magnetization may have been acquired during an impact process on the lunar surface—a magnetic field being provided by ionized gas (comet tail?), or more likely, by the breccia cooling in a magnetic field of unknown origin. Ilmenite(?) and metallic iron in breccias, and ferrous and metallic iron in glass beads separated from lunar fines, were identified by high-field and low-temperature experiments. The iron appears to occur in a wide range of grain sizes including the single domain and multidomain states.

The specific heats of lunar samples 10057 and 10084 returned by the Apollo 11 mission were measured by R. A. Robie, B. S. Hemingway, and W. H. Wilson (r0543) between 90° and 350°K using an adiabatic calorimeter. The samples are representative of the type A vesicular basalt and of the finely divided lunar soil. The specific heat of these materials changes smoothly from about 0.06 cal (g-deg)<sup>-1</sup> at 90°K to about 0.2 cal (g-deg)<sup>-1</sup> at 350°K. The thermal parameter  $\gamma$ , where  $\gamma = (k\rho c)^{-1/2}$ , which controls the cooling of the surface, will accordingly vary by a factor of about two between lunar noon and midnight where  $k$  is the thermal conductivity,  $\rho$  the density and  $c$  the specific heat. The specific-heat data permit a much more exact calculation of the synodic temperature variation of the lunar surface and will be useful in interpreting the proposed lunar heat-flow experiment.

G. B. Dalrymple and Doell found that the carrier of thermoluminescence (TL) in the Apollo 11 lunar samples is plagioclase feldspar. The TL observed in the lunar samples is the result of a dynamic equilibrium between acquisition from radiation and loss in the lunar thermal environment which suggests that TL disequilibrium could be a useful stratigraphic tool.

There is progressive change in TL with depth in the core-tube samples, and an anomaly in the flow curves between 7.8 cm and 10.5 cm identifies a surface buried by recent lunar surface activity. The age of burial is uncertain but probably occurred more than 1,000 years ago and may have occurred less than 10,000 years ago.

#### The lunar fine materials

M. B. Duke, C. C. Woo, M. L. Bird, G. A. Sellers, and R. B. Finkelman studied the size distribution and mineralogical constituents of the lunar fines (sample 10084). The rock constituents of the soil include breccia, igneous-rock fragments of basaltic affinity, glazed aggregates of various morphology, and exotic material such as transparent spheres, nonbasaltic igneous rock fragments, and meteoritic material. The breccia appears to represent a distinct rock unit, probably a welded impact breccia, and not simply fused soil. The major factor in formation of the soil is comminution, but the glazed aggregates represent constructional features. The finest size fractions of the soil are depleted in material, suggesting an active reconstitution process. The rock fragments in the soil are principally fine-grained varieties which may be different in composition from the larger rocks. A meteoritic component consisting of about 0.5 percent of ordinary chondrite must be added to breccia and rocks to explain the siderophile element content of the soil.

#### Impact metamorphism of lunar samples

Evidence of shock in lunar samples due to meteorite impact was studied by E. C. T. Chao, O. B. James, J. A. Minkin, J. A. Boreman, E. D. Jackson, and C. B. Raleigh.<sup>106</sup>

The Apollo 11 sample contains abundant fragments that have shock histories. On the basis of the progressive effects in plagioclase, shock effects shown by ilmenite-rich basalts may be classified as follows: (1) weak; no intragranular deformation in plagioclase; sparse lamellar mechanical twins in ilmenite and pyroxene; microfractures in all minerals; (2) moderate; mechanical twins, deformation lamellae, and shock lamellae in plagioclase; abundant mechanical twins in ilmenite and pyroxene; abundant microfractures in all minerals; (3) strong; partial or complete solid-state vitrification of plagioclase; intense fracturing and mechanical twinning in pyroxene and ilmenite; local lamellae of alternating high and low indices of refrac-

<sup>105</sup> Doell, R. R., Grommé, C. S., Thorpe, A. N., and Senftle, F. E., 1970, Magnetic studies of Apollo 11 lunar samples: Apollo 11 Lunar Science Conf., Proc., Geochim. et Cosmochim. Acta, Supp. 1, v. 3, p. 2097-2102.

<sup>106</sup> Chao, E. C. T., James, O. B., Minkin, J. A., Boreman, J. A., Jackson, E. D., and Raleigh, C. B., 1970, Petrology of unshocked crystalline rocks and evidence of impact metamorphism in Apollo 11 returned lunar samples: Apollo 11 Lunar Science Conf., Proc., Geochim. et Cosmochim. Acta, Supp. 1, v. 1, p. 287-314.

tion in pyroxene; (4) very strong; flowage in feldspar glass; (5) intense; melting of entire rock by shock-induced heating. Most mechanical twinning in plagioclase is parallel to (010); mechanical twinning in pyroxene is dominantly parallel to (001) and subordina- tely parallel to (100).

Most glass particles represent either mineral glasses of plagioclase composition that formed by selective shock vitrification or rock glasses that formed by shock-induced melting of entire rocks. Rock glasses have compositions of ilmenite-rich basaltic rocks, feldspar-rich rocks, or others not represented by the large rock samples returned.

On the basis of data from laboratory shock experiments, the Hugoniot elastic limit for Apollo 11 basalt is estimated to be about 50 kb; the boundary between weak and moderate shock is about 150 kb, and the boundary between moderate and strong shock is about 250 kb. (There are no data for higher pressures.) Post-shock temperature is estimated from rock textures to be about 700°C at the boundary between strong and very strong shock, and about 1,200°C at the boundary between very strong and intense shock.

#### **Preliminary examination of Apollo 12 lunar samples**

E. C. T. Chao, R. L. Smith, and R. E. Wilcox participated in the preliminary examination of Apollo 12 lunar samples at the Lunar Receiving Laboratory, Manned Spacecraft Center, Houston, Tex. The report of the Lunar Sample Preliminary Examination Team (LSPET) <sup>107</sup> shows that there is a wide variety of igneous rock types, in terms of crystal grain size, texture, and mineral proportion, among the Apollo 12 samples. Some of the rocks, such as picrite basalt and olivine gabbro, contain over 30 percent olivine. Others are very rich in pyroxene, typical for igneous rocks of cumulative origin. Many of the rocks show zoned pigeonite phenocrysts with augitic rims in a groundmass of plagioclase, pyroxene, and ilmenite, and with a variolitic texture suggesting rapid cooling. As suggested by the mineralogical composition and confirmed by chemical analysis at the Lunar Receiving Laboratory by R. S. Taylor, the Apollo 12 rocks are generally lower in titanium dioxide (3-6 weight percent) than the ilmenite basalts of the Tranquillity Base.

<sup>107</sup> Lunar Sample Preliminary Examination Team, 1970, Preliminary examination of lunar samples from Apollo 12: *Science*, v. 167, p. 1325-1339.



## REMOTE SENSING AND ADVANCED TECHNIQUES

### EARTH RESOURCES OBSERVATION SATELLITE (EROS) PROGRAM

During 1970 the Earth Resources Observation Satellite (EROS) Program of the U.S. Department of the Interior, in cooperation with the National Aeronautics and Space Administration (NASA), continued to determine the applications of airborne and spaceborne remote sensors to departmental resource inventory and management activities. In contrast to previous years, when most of the effort was concentrated within the U.S. Geological Survey, the year was marked by sharply increased participation by the Bureaus of Reclamation, Land Management, Mines, Indian Affairs, Outdoor Recreation, Sport Fisheries and Wildlife, Commercial Fisheries, and by the Federal Water Quality Administration and the National Park Service. The effort emphasized preparation for effective utilization of multiband image data which will be acquired from the NASA Earth Resources Technology Satellites (ERTS-A and B) when the initial satellite is launched in 1972.

ERTS-A, designed in part to Department of the Interior specifications, will contain a primary payload of three advanced (return-beam vidicon) television cameras operating simultaneously with each viewing the same scene in a different spectral band. The bands selected are the blue-green (475-575 nm), red (580-680 nm) and near-infrared (680-780 nm). The blue-green band was selected to provide maximum penetration of water and is expected to assist studies of lakes, estuaries, and continental shelf areas. The visible red band is the optimum band for discriminating cultural features and will aid in identifying crops. It is also an optimum band for discriminating rocks and soils in arid environments. The near-infrared band will assist in delineating water bodies, observation of land forms, and be useful for essential information on plant vigor. Other data systems will include an optical mechanical scanner operating in four bands from 0.4 to 1.0  $\mu$ m, a tape-recorder and radio-relay system designed to monitor ground-based measurement instruments such as stream water-level and water-quality recorders, volcano tiltmeters, and seismic event counters.

The satellite will be flown at an altitude of about 500

nautical miles in sun-synchronous near-polar earth orbit. It will repeat observations over any single point on earth every 17 to 21 days, depending on the exact orbit altitude that is selected. It will provide coverage under near-identical sun-angle conditions so that changes in spectral characteristics can be used to analyze dynamic processes on earth.

It has been determined that image data from ERTS-A and B will be immediately applicable to the U.S. Department of the Interior resource problems where synoptic overview of large areas and repetitive coverage are required. Typical examples are the assessment of damage of the 1964 Alaskan earthquake and the more recent problems of monitoring oil leaks and slicks in the Santa Barbara Channel, Calif. (1969), and the Gulf of Mexico (1970). With regard to the latter accidents, the EROS Program was intimately involved in providing photographic data on which departmental management decisions on oil spills could be based.

A special resource study using high-altitude color infrared photography of the NASA Mississippi Test Facility was conducted at NASA's request to provide management officials with information on which to base decisions for future use of the site. A second special study, aimed at evaluating current sensor applications to pollution problems, is now underway.

Studies of Apollo 9 multiband photography revealed a part of the Ouachita River in flood at the Louisiana-Arkansas border. Enhancement procedures conducted by the Cartographic Applications Program clearly separated the river channel from the flooded area for analysis of boundaries and extent of inundation. The Alabama Geological Survey published studies showing linear features crossing the valley and ridge structures of central Alabama. One such feature was determined to be a fracture system intersecting the Logan Martin damsite on the Tallapoosa River and is suspected of being the source of leakage problems associated with the dam. By plotting known water well and stream recording stations in relation to the linear features, hydrologists were able to devise a plan for the placement of additional monitoring stations that will im-

prove their knowledge of ground- and surface-water movement in the State.

The EROS Program has defined several resource-oriented products to be generated when ERTS-A imagery becomes available. These include:

1. Regional-scale photoimage maps of large segments of the earth's surface;
2. Land-use maps of the United States, updated on a yearly basis;
3. Maps and statistical data relating to distribution of surface water in the United States;
4. Maps and statistical data relating to the distribution of vigorous vegetation of the United States, including a number of specialized products such as crop and rangeland forage maps which would be expected to be of direct benefit to those engaged in range use and management;
5. Maps showing distribution of snow and estimates of accumulation and melt rate of snow derived from successive coverages; and
6. Maps and related analyses of urban growth patterns.

Other special products will include maps showing the distribution of sediment in estuaries and the changes that take place with changes of tide, storm, and season. This type of information should prove useful to the fishing industry in general and especially to those involved in shrimp fisheries.

Under contract to the EROS Program, the Radio Corporation of America continued to conduct detailed studies of data requirements foreseen by the Tennessee Valley Authority and Desert Research Institute of the University of Nevada. In addition, site and radio-interference surveys of a large area in the central United States were conducted to determine a suitable location for a satellite data-receiving station. Four cities in Iowa, Nebraska, and South Dakota were determined to be geographically well located to receive a maximum of satellite-obtained data and to have desirable logistic and local resource characteristics. From these, Sioux Falls, S. Dak., was selected by President Nixon to be the site of the data center. Detailed design of the facility should be completed and construction started in early 1971 in order to insure adequate and timely distribution of ERTS-A data in 1972. NASA facilities at Fairbanks, Alaska, Greenbelt, Md., and Corpus Christi, Tex., will be primary reception centers in the experimental phases of the program.

Through NASA funding distributed by the EROS Program, a number of feasibility studies were con-

ducted by other bureaus of the Department of the Interior. Several of these are described below:

The Bureau of Mines studied Gemini and Apollo space photography to determine changes in waste dumps and open-pit mining at the Twin Buttes copper pit near Tucson, Ariz. Not only were changes detected from repetitive observations at altitudes of 125 nautical miles and more, but stereoscopic measurements permitted rough calculations of the total cubage removed from the pit.

The Bureau of Reclamation initiated two projects during the year: (1) in Oregon, to determine irrigation suitability by remote sensing in a semiarid environment; and (2) in the PaMong Valley, Thailand, to determine irrigation suitability of laterite soils in a tropical environment. These are continuing projects of several years' duration.

Data acquired by airborne multiband sensors in Oregon are being processed prior to analysis and evaluation. A contract study by the Raytheon-Autometric Co. analyzed the problems to be encountered in the Thailand area and recommended a data-acquisition plan and procedure.

The Bureau of Sport Fisheries and Wildlife initiated a remote-sensing study of the prairie potholes of South Dakota to determine the feasibility of monitoring the ecology of the wetland and upland game areas as they relate to duck nesting grounds and other game-bird populations. Seasonal data were acquired and are undergoing analysis at the Remote Sensing Institute, South Dakota State University, Brookings, S. Dak.

The Raytheon-Autometric Co., under contract to the EROS Program, conducted a study of photography taken by Apollo 9 and by airborne sensors at high altitudes of an area in eastern Arizona for the Bureaus of Indian Affairs, Land Management, and Reclamation. The purpose was to determine the degrees of interpretability for photography in several spectral bands and at several levels of resolution (100, 200, and 300 feet). The study was successful in providing these Bureaus with visual examples of what they can expect from ERTS data and in defining the types of resources information that can be extracted therefrom.

The EROS Program helped support a study by members of the Department of Natural Resources of the State of Washington to evaluate the utility of the proposed ERTS and EROS Programs as information sources for operational State agencies and academic institutions. Management and research personnel from most natural-resource and land-use oriented State agencies as well as research personnel from the two



major State academic institutions (University of Washington and Washington State University) participated in the project.

High-altitude, small-scale photographs, both singly and in mosaic form, were used to simulate ERTS imagery. Participants were asked to relate their data needs to the proposed ERTS imagery and the timeliness of satellite surveillance.

The following conclusions and recommendations were made from the State of Washington study:

1. Significant data use of ERTS imagery can occur at the State level. Recommendation: NASA and U.S. Geological Survey should proceed rapidly to the ERTS-A experiment.
2. Potential users generally have limited knowledge of the availability of aerial photography and how to order it. Recommendations: (a) Immediate development of regional EROS data centers. (b) Inventory the existing State agencies responsible for providing aerial photography.
3. Potential users generally have limited knowledge of how to use aerial reconnaissance data. Recommendation: Develop EROS user manuals.
4. ERTS imagery simulation process used in this study was poor. Recommendations: (a) Use actual ERTS-A imagery for future user inventories. (b) Develop a catalog of standardized infrared color imagery.
5. Most potential users are oriented to legal ground descriptions. Recommendation: Provide ERTS imagery and desired maps with common coordinates (township and range) as well as special coordinates as needed.
6. Satellite relay of ground sensor data would be significant to many users. Recommendation: Coordination and installation of relay transmitters should be a part of the regional data center function.

## APPLICATIONS TO GEOLOGIC INVESTIGATIONS

Application of remote-sensing studies to the U.S. Geological Survey (USGS) program in geologic mapping and analysis continued in cooperation with the National Aeronautics and Space Administration (NASA). A greater emphasis was placed on an interdisciplinary approach of physics and geology in the development of remote-sensing techniques and potential satellite applications. This approach involved the development of mathematical models based on appropriate physical laws and physical properties which

match remote-sensing observations made at selected geologic target areas. Empirical studies are also being continued to gather results of intrinsic value and to extend the interdisciplinary approach to geologic application.

## DEVELOPMENT OF PHYSICAL MODELS AND TECHNIQUES

### Detection of limestone and dolomite bodies from infrared imagery

Examination of thermal infrared images (8–14  $\mu$ ) from the Mill Creek, Okla., test area by L. C. Rowan, T. W. Offield, and P. J. Cannon, obtained through the NASA-Earth Resources Survey aircraft program, led to the discrimination of relatively pure limestone and dolomite for remote geologic mapping. Bedding detail is sufficient for determination of folds and faults, and some faults not otherwise exposed are shown by infrared images. In areas of low relief, bedding detail is enhanced in morning images; where moderate-relief topography is a reflection of formation distribution, contrast at the scale of geologic formations is conspicuous in the afternoon images. Fracture zones appear as thermal lows, apparently because of water saturation and concomitant transpiration. The existence of thermal lineaments apparently unrelated to topographic or ground-water effects is not yet explained but illustrates an important application of infrared measurements to structural geologic investigations.

### Studies of temperature variation as a function of rock properties

A mathematical model was constructed by Kenneth Watson to treat diurnal temperature variation as a function of rock properties (thermal inertia, albedo, emissivity), atmospheric effects (transmission, air temperature), site location (latitude), and season (Sun declination). The model provides a satisfactory explanation of differences between limestone and dolomite recorded in the thermal infrared images of the Mill Creek site when representative thermal inertia and albedo values are used. A second mathematical model was constructed to examine the effects of topographic slope on reflected and emitted energy. For values of the latitude and Sun declination appropriate to the Mill Creek overflight, the model gives a qualitative agreement with the daytime image and photographic data. The results will be useful in predicting optimum observation times to enhance or diminish topographic effects on infrared images.

Infrared reflection measurements at a small specular angle ( $8^\circ$ ) were made of well-rounded, monodispersed  $\alpha$ -quartz ranging in size from very fine to coarse sand

to provide a controlled set of observations for Watson to match with theoretical scattering models. The results stemming from use of spherical grains, narrow size distribution, and size ranges corresponding to terrestrial sand environments differ from results reported where angular grains at somewhat smaller grain sizes and with much larger size-distribution limits were used. Only qualitative matching is possible between observation and the most sophisticated theoretical model yet proposed.

#### **Influence of surface coatings on infrared spectrum of quartz**

R. D. Watson extended his study of the effects of surface coatings to include the influence of individual coatings of water and frost on the diagnostic infrared spectrum of quartz. Masking of the  $12.5\text{ }\mu$  emission minimum of quartz by the water film illustrates the need for detailed understanding of the effects of surface coating when remote-sensing observations are applied to discrimination of rock-types.

#### **Application of data from a space satellite to regional crustal analysis**

Analysis by Isidore Zietz of proton magnetometer measurements from the U.S.S.R. Cosmos-49 satellite during the period from October 24 to November 3, 1964, provided a good example of the application of satellite observations to regional crustal analysis. The observations which were made between lat  $50^\circ$  N. and  $50^\circ$  S. and at altitudes ranging from approximately 261 to 488 km were averaged in the squares of a  $3^\circ$  grid, and the main dipole field was removed. Residual anomalies are less than 100 gammas and appear to be consistent with belts of broad anomalies that are known from surface and near-surface magnetic measurements. Correlation of the residual anomalies with broad geologic provinces is good. A series of magnetic lows across the continental United States agrees in position with a proposed rift extending from the Cape Mendocino fracture off the west coast area to the wrench fault system proposed by Drake and Woodward<sup>108</sup> in the east coast area. In the Western United States, large amplitude magnetic lows are associated with the Basin and Range and the Northern Rocky Mountains provinces; both regions are characterized by high heat flow, similar crustal structure, and tectonic activity during Cenozoic time. Most of central Wyoming, central Montana, and the area of the Colorado Plateaus is characterized by normal heat flow and generally positive magnetic anomalies.

<sup>108</sup> Drake, C. L., and Woodward, H. P., 1963, Appalachian curvature, wrench faulting, and offshore structure: *New York Acad. Sci. Trans.*, v. 26, ser. 2, p. 48-63.

#### **Computer processing of multispectral data for mapping terrain units**

Digital computer processing at Purdue University of 12 wavelength bands of visible and reflective infrared scanner data, done in support of studies by H. W. Smedes and K. L. Pierce in Yellowstone National Park, resulted in successful automatic computer mapping of 8 terrain units, with greater than 80 percent accuracy. Target areas in the scene were selected for training the computer. Statistical parameters of reflectance such as mean, standard deviation, and  $12 \times 12$  covariance matrix were computed at each channel (wavelength) for each category of material. These data were analyzed to determine those channels most useful for recognition of all object categories studied and to classify all the remaining data points into the known categories. The following object categories have been mapped with greater than 80-percent accuracy in a 12-sq mi area with 1,800 feet of relief: bedrock exposures, talus, vegetated rock rubble, glacial kame, glacial till, forest, bog, water, and shadows. In addition, comparative studies were made of the effectiveness of the proposed Earth Resources Technology Satellite (ERTS) data channels and the computer-selected best four channels in the automatic recognition and mapping of the same terrain types using the same set of data. These simulations resulted in maps whose accuracies were only a few percent less than those obtained from the best set of four channels, thus indicating that the ERTS data channels are likely to be highly successful for terrain analysis of a wide variety of categories encompassing a broad range of spectral reflectance. These studies also indicate that, for the broad range of terrain categories, many combinations of three or four channels of data would be equally satisfactory.

### **EMPIRICAL STUDIES**

#### **Location of ore deposits by remote sensing**

Color and color infrared photography, thermal infrared imagery ( $8\text{--}14\text{ }\mu$  and  $3\text{--}5.5\text{ }\mu$ ) and ultra-violet imagery were obtained of the Goldfield mining district, Esmeralda and Nye Counties, Nev., to evaluate remote sensing as a guide in exploration for ore deposits. Studies by R. P. Ashley show that volcanic flow and pyroclastic rocks of various compositions, areas of hydrothermal alteration, structural patterns, and wastes from previous mining can all be recognized in conventional color photography. Color infrared photographs which are more responsive to vegetation effects were of some value for interpreting the nature of mining wastes—dumps containing sulfide minerals

support no vegetation. The thermal infrared images evaluated by R. J. P. Lyon and Attila Kilinc (Stanford University) were useful in determining structural patterns but not in determining rock type or recognizing hydrothermal alteration.

#### **Mapping of lineaments and coastal features from Apollo spacecraft photography**

Mapping of lineaments of Apollo 6 photography of southern Arizona and New Mexico by S. J. Gawarecki has shown that fracture zones persist from range to range along strong northwest, north-northeast, east-northeast, north-south, and somewhat weaker east-west trends. The Tyrone and Santa Rita, N. Mex., copper deposits lie on the same east-northeast-trending fracture zone at intersections with separate northwest-trending fracture zones. The Pima, Mission, Twin Buttes, and Esperanza copper mines south of Tucson, Ariz., lie across another broader east-northeast-trend at an intersection with an east-west-trending fracture zone. Examination of Apollo 6 stereophotographs reveals what appear to be very large landslides on the southwestern flank of the Sacramento Mountains of south-central New Mexico. At least two toreadora-block slides are present and form scallop scarps, each nearly 6 miles in length, which control the bed of the Sacramento River.

Photographs from Apollo 9 were particularly useful in delineating coastal features of the Southeastern United States.

Five coastal scarps on relict barrier shorelines of probable Pleistocene age were recognized and correlated with known strandlines in Georgia and South Carolina by Gawarecki on a color infrared frame of the South Carolina coast. The Carolina Bays were particularly well portrayed and easily mapped with this type of film. Black and white infrared photography of the Georgia coast outlined all marshy areas, significant drainage, and flood plains that are not normally visible on conventional photography. A similar infrared photograph of the Atlanta, Ga., area uniquely shows strong detail of the Brevard fault zone, among lineaments, and to some extent, the effects of folds on drainage in the Piedmont province.

#### **Detection of lineaments from radar mosaics**

A series of northwest-trending lineaments in the Berkshire area and in the area north of the corner of Rhode Island, Connecticut, and Massachusetts were recognized by L. R. Page and his coworkers on the X-band side-looking radar mosaic of Massachusetts. West of this corner distinctive truncations of north-trending lineaments are probably extensions of

faults that have been recognized farther east in Massachusetts.

#### **Mapping of shoreline sediments and currents from aerial photography and infrared imagery**

Apollo 9 photographs of the south Texas coast, examined by H. L. Berryhill, Jr., reveal suspended sediment and two opposing longshore-current patterns with remarkable detail. A southward-flowing current nearshore is paralleled by a northward-flowing current farther out. Repetitive monitoring of some coasts from an orbiting satellite should permit routine observation of sediment movement as related to tidal and seasonal change in current patterns.

J. D. Friedman, working with L. R. Page, J. S. Schlee (all USGS), and R. S. Williams, Jr. (U.S. Air Force Cambridge Research Laboratories), initiated a series of airborne thermal infrared line-scan and photographic surveys yielding thermographic imagery and cartographic quality Ektachrome and Ektachrome infrared aerographic film coverage in a 9×9-inch format at a scale of 1:24,000 over Quaternary coastal areas and islands of Massachusetts for the purpose of studying temporal changes in shoreline and tidal zone processes of erosion and aggradation. Parts of Penobscot Bay and the Sommes Sound area, Maine, were flown in 1969. Preliminary analysis indicated that the Ektachrome infrared film (type 8443) is particularly useful in delineating shallow subaqueous features of the intertidal zone. Because of the marked sensitivity of the cyan dye layer to changes in near-infrared reflectance from shallow bottom features and because of the sensitivity of the yellow dye layer to reflectance in the green spectral region, better water penetration qualities for Ektachrome infrared film resulted than were heretofore reported. Morphologic features of the intertidal zone recorded in mappable detail included: (1) details of bottom dredging at Wellfleet, Mass., (2) northeastern submarine extension of Great Point, Nantucket, Mass., (3) subaqueous extension of beach cusps in Nantucket Harbor, (4) a submerged offshore bar east of Cape Cod, Mass., and (5) offshore sand-wave-type ripple marks near Brewster, Mass.

Off Cape Cod, coastline changes of Monomoy Island since 1964, plotted at a scale of 1:24,000 from 9×9-inch Ektachrome infrared photographs, suggest to J. D. Friedman, R. N. Oldale, and R. S. Williams, Jr., that coastal erosion continued by longshore drifting, particularly marked at the narrow waist of the island. If erosion continues at the present rate, the island could be bisected 3 miles above Monomoy Point in 70 years. Deposition was concurrently extending Monomoy Point to the south at the rate of 40 feet a year between 1964

and 1969. More extensive changes were recorded for the western end of Nantucket Island and Cape Pogue elbow of Chappaquiddick Island, Mass.

#### **Studies of geothermal and volcanic areas by aerial photography and infrared imagery**

*Iceland.*—In a continuing remote-sensing study of the Reykjanes geothermal area in Iceland, J. D. Friedman and others found that the Reykjanes geothermal field is related to an east-northeast-trending volcanic fracture system, and is located partly on the northwest flank of a small shield volcano, Skálafell, within the Reykjanes-Langjökull neovolcanic zone. The area of superficial hydrothermal activity, consisting of steam springs, boiling mudholes, hot brine springs, hot and hydrothermally altered ground, is about  $3 \times 2$  km. The hot circulating ground water in the geothermal field is brackish to a considerable extent and, after exploration drilling in 1969, spouts with eruptive force giving off a dispersed mixture of flash-boiling brine and steam. The temperature of liquid at the bottom of a recently completed 1,100-m exploration borehole is  $286^{\circ}\text{C}$ . A 0.5-m depth subsurface-temperature map of the entire Reykjanes geothermal area, completed late in 1968, shows close correlation with position and magnitude of infrared anomalies at the surface. In 1969, an incremental heat-flow map was constructed from the subsurface-temperature map, utilizing New Zealand data of Dawson<sup>109</sup> which relates total heat flow in an area where convection predominates, to shallow subsurface temperatures. The total heat flow to the surface at Reykjanes and conductive heat transfer through thick tephra crater rims reached a peak during late summer.

Photographic reconnaissance flights over the volcano Surtsey by J. D. Friedman in September 1969 confirmed reports of a buildup in thermal emission from the northern part of the island during mid-1969. An increase in vapor emission from Surtur II fracture systems and the Surtur II vent area is revealed by the photographs. Convective and conductive heat transfer through thick tephra crater rims reached a peak during late summer.

To further the understanding of the study of thermal phenomena by remote-sensing techniques, a cooperative agreement between the Geological Survey and the U.S. Air Force Cambridge Research Laboratories (AFCRL) with the participation of the National Energy Authority of Iceland has been in effect since 1966. As one result of this continuing program, Fried-

man (USGS), working with Gudmundur Pálmason, Jón Jónsson, and Kristján Saemundsson (National Energy Authority of Iceland), and R. S. Williams, Jr. (AFCRL), estimate that, on the basis of thermal infrared observations of the Reykjanes, Iceland, geothermal area made with an InSb detector and magnetic tape recording, the minimum detectable anomaly is equivalent to 200 to  $700 \mu\text{cal}/\text{cm}^2 \text{ sec}$  convective heat transfer at the earth's surface. This threshold of detectability was virtually confirmed by a second method—measurement of the smallest discernible radiation-temperature differences above background levels, utilizing surface-temperature-controlled isodensitracer scans of infrared imagery of cool parts of Surtsey. A radiative flux difference of  $700 \mu\text{cal}/\text{cm}^2 \text{ sec}$  was observed between basalt tephra (emissivity = 0.985) and ocean water (emissivity = 0.995). Smaller heat-flow differences should be detectable by the airborne scanner, when a uniformly high emissivity medium (for example, water) is observed.

Utilizing earlier observations (J. D. Friedman and others, r0118) of infrared anomalies in the neovolcanic zone of Iceland, P. L. Ward (Lamont-Doherty Geological Observatory) and Sveinbjörn Björnsson (National Energy Authority of Iceland) reported a strong coincidence between occurrence of microearthquakes, as determined by tripartite arrays, and infrared anomalies recorded by airborne scanner. Infrared anomalies and microearthquakes were both recorded at Reykjanes, Krísuvík, Kverkfjöll, and Krafla, where microearthquakes are associated with fracture systems along which circulating ground water convects heat to the surface. At Hekla and Theistareykir, where a large number of infrared anomalies were recorded, no significant number of microearthquakes were reported by Ward and Björnsson. These data suggest that the thermal anomalies in these two areas are waning. In one area east of Reykjanes, in the southwest end of the lake Kleifarvatn, microearthquake concentrations at depths of 3 to 4 km coincided spatially with a distinct infrared lake-surface anomaly, but evidence of a significant thermal anomaly on the basis of water-surface temperature data was lacking.

*Mexico.*—A study of airborne thermal infrared line-scan imagery and Ektachrome and infrared Ektachrome aerographic photography of the Los Negritos-Ixtlan de los Hervores geothermal fields, located east of Lake Chapala at the intersection of the Sierra Madre Occidental and the west-central segment of the neovolcanic axis of Mexico was completed by J. D. Friedman and S. J. Gawarecki, working with R. Gomez Valley (Mexican Institute of Investigations for the Electrical

<sup>109</sup> Dawson, G. B., 1964, The nature and assessment of heat flow from hydrothermal areas: New Zealand Jour. Geology and Geophysics, v. 7, p. 155–171.

Industry) and J. C. Banwell (Geological Survey of New Zealand). Two principal zones of hydrothermal activity occur here in a tectonic trench filled with Quaternary lake sediments which are intercalated with Quaternary volcanic material and characterized by an intricate system of block faults (part of the Chapala-Acambay tectonic system) along which volcanism has been active in modern time. Surface manifestations of geothermal activity consist of relatively high heat flow, hot springs, small geysers, small steam vents aligned along an east-west axis at Ixtlan (possibly at the intersection of major fault trends), and mud volcanoes and hot pools aligned northeast-southwest at Los Negritos.

More than 20 exit points of thermal waters visible on infrared imagery appear to be aligned along an extension of the Ixtlan fault between Ixtlan and El Salitre. A narrow zone of hydrothermal alteration and deposition at the surface is identifiable on the infrared imagery of this area, closely related spatially to an electrical resistivity low at depth.

*Chile.*—Photographs of the Andes and Atacama Desert of Chile examined by S. J. Gawarecki showed that the younger volcanoes were generally found on the west side of the volcanic belt, suggesting a migration of volcanic activity in that direction. Photographs of the Antofagasta area show a major fault roughly parallel to the coastline that is cut by three west-northwest-trending faults producing apparent left-lateral effects. A widespread pattern of northeast-trending fracture zones is present that may represent complementary shear fractures to west-northwest faults. Comparison of space photographs of the Andes with air navigation charts shows that the former can be used to significantly upgrade the quality of the charts. Future stereophotographic coverage of South America from space should be very useful in this respect.

#### **Spectral reflectivity of foliage in a zinc-lead district**

A study begun in 1962 to examine differences in the spectral reflections ( $0.38\text{--}1.2\text{ }\mu\text{m}$ ) of tree foliage in the zinc-lead district of southwestern Wisconsin was completed by C. E. Olson, Jr., and H. T. Shacklette. Eight deciduous tree species growing in geochemically anomalous sites and in background sites were selected for study. Differences in average leaf reflectance that were statistically significant at the 0.1-percent level and which appeared to be site related were noted for some species. Correlation, however, between the measured reflection differences and the partly completed chemical analysis has not been achieved at this date.

#### **Tracing of waterborne dye with a Fraunhofer-line discriminator**

Operational airborne tests of the prototype Fraunhofer-line discriminator conducted over San Francisco Bay and San Pablo Bay, Calif., the Pacific Ocean near the Golden Gate, and the Colorado River north of Needles, Ariz., demonstrated to G. E. Stoertz and W. R. Hemphill that Rhodamine WT dye in concentrations as low as 1 ppb could be detected. The discriminator which is an optical-mechanical device that detects daytime luminescence appears to have application in dye tracer studies involving water quality, distribution of sediment, and rate of pollution dispersion in rivers and estuaries, as well as in the direct detection of materials that exhibit natural luminescence, such as oil slicks, pulp mill waste, and some minerals in well-exposed outcrops.

## **APPLICATIONS TO HYDROLOGIC INVESTIGATIONS**

#### **Multispectral remote sensing of urban features**

J. E. Colwell<sup>110</sup> (University of Michigan) made an investigation for the U.S. Geological Survey and NASA to determine the percentage of imperviousness in a selected suburban area having a wide range of surface cover (houses, streets, vegetation, soil, and water). Multi-spectral data were collected in three separate sets, each containing information from different spectral regions. The data were processed on special-purpose analog and digital computers, and the results were presented in the form of recognition maps, resolution-element counts, and mean-reflectance spectra. The spectral interval from  $1.0\text{--}5.5\text{ }\mu\text{m}$  provided the most promising single data set. Results suggest that information concerning the area and distribution of the materials present in an urban scene can be most reliably and completely obtained by the simultaneous processing of both reflected and emitted data.

#### **Snow and ice sensing with passive microwave and ground-truth instrumentation, South Cascade Glacier, Wash.**

Passive microwave sensing is a tool of great potential value for remote monitoring of glaciers and snowpacks. It may be possible to distinguish between many different snowpack properties through the use of selected sensor wavelengths and polarizations. A field and laboratory program, conducted by M. F. Meier

<sup>110</sup> Colwell, J. E., 1970, Multispectral remote sensing of urban features: Univ. Michigan, Willow Run Laboratories, Rept. 2772-6F, 19 p.

(USGS) and A. T. Edgerton (Aerojet-General Corp.), and sponsored by the U.S. Geological Survey and NASA, is in progress to determine the microwave emission characteristics of snowpacks. The object of this study is to determine the feasibility of using microwave radiometry for monitoring meaningful hydrologic properties of snowpacks and glaciers.

Field experiments were conducted in the Pacific Northwest to assess the effects of melting, layering, surface roughness, and density variations on microwave emission and to determine the effective penetration of microwave sensors of varying wavelengths. During this study, the investigators experienced difficulty in obtaining reliable ground-truth measurements of snow moisture. To improve confidence levels in this measurement, a series of detailed tests was conducted in the South Cascade Glacier where several techniques for determining snow moisture were compared.

The investigators are also analyzing 1.55-cm imagery of Mount Rainier, where effects of terrain slopes, parallel and perpendicular to the flight line, are found. These data correspond to a variety of snow and ice conditions.

NASA P3V overflights of the South Cascade Glacier conducted during Mission 78 provided, for the first time, thermal infrared imagery of subfreezing snow. The 8- to 14- $\mu$ m imagery indicated cold snow concentrated in very shallow valleys on the glacier, suggesting the existence of shallow surface drainage winds.

#### **Thermal survey of the Connecticut River estuary**

F. H. Ruggles, Jr., analyzed airborne infrared data of the Connecticut River estuary obtained September 8 and 9, 1968. The data were obtained during various conditions of tidal flow to determine the capability of infrared-thermal mapping systems to delineate the extent of thermal loading. Flights were made by the HRB-Singer Co., under contract with the U.S. Atomic Energy Commission, using the Reconofax IV Infrared-Thermal Mapping System and an AR-2 infrared radiometer boresighted to the centerline of the scanner and operated simultaneously in the 8- to 14- $\mu$ m range, at altitudes of 1,000 and 2,000 feet during both daylight and evening hours. An 8- $\mu$ m LP filter was used during the daylight hours.

During the daylight period of September 9, 1968, Travelers Research Corp. secured water-temperature data using portable electric thermometers. A comparison of the temperature data indicates that the radiometer readings are about 3.8°C cooler than the electric thermometer data. Thermal loadings were easily identi-

fied on the film, and density differences are identifiable at the mouth of the estuary on Long Island Sound.

Isodensitometry analysis of the data will be compared with isotherms mapped using the electric thermometer data and the infrared imagery data.

#### **Remote sensing in water-resources studies in Yellowstone National Park, Wyo.**

Data obtained from aircraft missions in August 1966 and September 1967 are being studied by E. R. Cox to locate bodies of cool ground water near thermal-water areas in Yellowstone National Park, Wyo. Test areas are being established where hydrologic ground-truth data can be obtained to correlate with thermal infrared imagery.

Areas that show promise for correlation of imagery and ground-truth data are near Old Faithful, Fountain Paint Pot, Shoshone Lake, Norris Junction, and West Thumb. Patches of snow observed in April 1969 near Old Faithful and Fountain Paint Pot correlated exactly with relatively cool areas interpreted from infrared imagery. A snowline across Nez Perce Creek valley near Fountain Paint Pot correlates with a boundary between cool and warm ground water that was determined from augered test holes. In June 1969, traverses were made with a portable radiation thermometer, and temperature measurements were made in the upper 6 inches of the soil zone with a thermistor-type thermometer. These traverses showed the boundary between cool and warm ground water in Nez Perce Creek valley.

Additional remote-sensing data, particularly low-altitude infrared imagery and infrared photography, are needed in areas where hydrologic ground-truth data are available.

#### **Locating areas of potential sinkhole collapse**

In studies of the Bartow area, Florida, A. E. Coker (r1387, r1723) showed that it is feasible to use multispectral remote-sensing techniques to locate areas of future sinkhole development. Data recorded in various combinations of 18 spectral bands with an airborne multispectral scanner revealed, after special processing, distinctive terrain temperature patterns and moisture-stressed vegetative patterns that correlate with areas of known sinkhole formation. Areas of potential sinkhole collapse can be delineated where similar patterns are observed.

#### **Recognition of influent and effluent streams by side-looking radar**

G. L. Feder and J. H. Barks have determined that Logan Creek, a tributary of the Black River, is one of the outstanding examples of a losing stream in the carbonate terrane of the Missouri Ozarks. Water lost

in the upstream part of the valley resurges in Blue Spring in the Current River basin as well as in the tower portion of Logan Creek. Most of the approximately 20 miles between the upstream part of the stream and the point of resurgence contains no flow except during severe storm events.

Analysis of side-looking radar imagery of a part of the Missouri Ozarks indicated that losing streams can be identified by the lighter tones and smoother textures of their basins when compared to surrounding basins. The tonal and textural differences are due to less dissection in losing basins as a result of greatly reduced surface runoff from the basins. This difference was first recognized in the contrast between Logan Creek and normally acting basins nearby. Runoff characteristics determined from seepage runs in other valleys in the Ozarks with contrasting streamflow characteristics fit the pattern that Logan Creek showed on radar.

#### **Infrared radiometry for measuring inflow to streams**

A convective heat budget was used by E. F. Hollyday to calculate ground-water inflow to small alluvial streams on the Delmarva Peninsula, Md.-Del. Stream temperatures were measured with a radiometer from a helicopter flying along a stream; upstream discharge and the temperature of ground-water inflow were measured by a ground team. Ground-water inflow to a reach of Beaverdam Creek near Milton, Del., was calculated to be 5.7 cfs, which agrees within 11 percent of inflow determined by standard direct measurement techniques. Compared with the standard technique, time for data collection was greatly reduced.

In studying the application of remote sensing to the measurement of ground-water inflow to streams in the Delmarva Peninsula area, Hollyday found that minimum daily air temperature has good correlation with minimum daily water temperature of a small stream with large ground-water inflow. Minimum daily water temperatures for February and March 1969, recorded by thermistor thermograph were correlated with minimum daily air temperature reported by the Federal Aviation Administration weather station 7 miles away. Ninety percent of the measured minimum daily stream temperatures were within 1.5°C of the temperature determined by correlation.

#### **Lake hydrology studied by combination of remote-sensing methods**

By analysis of airborne infrared imagery and radiometry, and of conventional aerial photography, J. M. Whipple noted that this synoptic, repetitive viewing

acquired data heretofore unobtainable. For example, infrared imagery of Onondaga Lake, N.Y., delineated a reverse flow through the lake outlet. This had been tenuously suggested previously by algae identification and current measurements, but had never been documented or delineated. Both infrared imagery and photography of Oneida Lake, N.Y., show wind streaks. Quantitative geometric and thermal measurements necessary for study of Langmuir circulations can be made from these data when correlated with meteorologic and ground data. This study also is determining modifications of instrumentation and procedures needed to adapt remote-sensing techniques for routine use in areal investigations.

J. W. Stewart found that remote sensing from aircraft has useful application in lake studies of west-central Florida. Thermal infrared imagery and photography in the visible and near infrared range of the electromagnetic spectrum provide a detailed synoptic record over a large area during a near-instantaneous time interval, and may be repeated later for temporal evaluation. The data are also useful for (1) water storage inventories, (2) determination of the type, source, and rate of water body eutrophication, (3) delineation of vegetative zones related to soil moisture and declining lake levels, and (4) providing an insight into subsurface drainage, such as sink drains and artesian springs.

Infrared imagery (8–14  $\mu\text{m}$ ) is useful in identifying thermal anomalies that may be the result of artesian flow, water circulation, and water depth. The identification of ground-water discharge into a surface water body is dependent upon a temperature difference, which probably is maximum from December through February. At this time the ground water will be warmer than the surface water, therefore less dense, and will rise to the surface. Other thermal anomalies noted were related to the daily heat balance in that objects and vegetation of heavy mass tended to hold heat longer and appear warmer on the predawn imagery than those of small mass. For example, an asphalt road appeared warmer than a sand road, and moist soils tended to appear warmer than dry soils.

Both natural color and infrared color photography were obtained for this study. The color infrared photography was preferred (1) in hydrologic studies based upon vegetative indicators, (2) in delineation of shoreline boundaries, and (3) in qualitative evaluations of depth and turbidity. However, color infrared photographs appear unnatural because healthy vegetation is a shade of red, and turbid water tends to be a shade of pale green or pale blue. Natural color pho-



tographs provide an image similar to that sensed by the human eye and are a helpful addition for proper interpretation of phenomena represented on the color infrared photographs.

#### **Application of remote sensing to permafrost studies**

W. W. Barnwell and Chester Zenone completed their initial evaluation of infrared imagery of the Anchorage area, Alaska. The investigators believe that the heat-sensing capability of the infrared systems may be profitably applied to hydrologic studies in permafrost regions. In arctic regions such as northern Alaska, where the ground is permanently frozen except for a thin surface zone which thaws during a short summer season, adequate year-round water supplies are difficult to locate. However, unfrozen water bodies are sporadically distributed at shallow depths. This water may occur in springs on the lower slopes of hills, as shallow ground water in the alluvium of major rivers, or below surface ice in deep lakes or deep reaches of streams. Where there is free water, large temperature contrasts will exist between the water and the ambient air temperature. The thermal anomaly thus produced may possibly be detected by the heat-sensing infrared system.

#### **Applications of space photography to hydrologic and geologic problems**

Four multispectral photographs of east-central Alabama were made by the crew of the Apollo 9 spacecraft. The photographs cover a 6,400 sq mi area (about 80×80 miles square) between Birmingham, Ala., and the Georgia State boundary. The most significant features observed on the photographs, which were studied by W. J. Powell, C. W. Copeland, and J. A. Drahovzal (r2021), are relatively straight long lineations that intersect Appalachian structural axes. Apparent coincidence of the linear features with areas of known

anomalies of streamflow, of large-capacity wells and springs, quarry drainage, and dam leakage problems indicates that lineations may not have only a marked geologic effect but may also have great hydrologic, environmental, and economic significance. The interpretations made on the photographs indicated the following applications: (1) determining areas of (a) ground-water movement, (b) abundant ground-water availability, (c) suitability for making low-flow measurements, and (d) suitability for locating gaging stations; (2) locating sites of optimum hydrogeologic conditions for the construction of dams and reservoirs; and (3) aiding in geologic mapping and in the study of structural geology of an area.

#### **Multispectral remote sensing of the Everglades, Fla.**

A. L. Higer, N. S. Thomson, F. J. Thomson, and M. C. Kolipinski (r2591) processed multispectral remote-sensing data and found that sufficient recognizable plant species and other targets permitted them to identify approximately 90 percent of the area within a strip 7 miles long by about 2,000 feet wide in Everglades National Park, Fla. These targets include various water depths, densities of sawgrass, trees, and mats of algae.

Multiband imagery shows potential in extracting the spectral signatures for hydrobiological communities as well as for individual species. The anticipated benefits of future research in this field are (1) detailed, automatic, hydrobiologic mapping of large regions of marsh, swamp, shallow inland water, and coastal regions of the country, (2) identification of water characteristics through indicator plant species, possibly automated by electronic recording and processing of data, and (3) development of remote-sensor techniques to monitor hydrologic phenomena, so that data for operational needs become available soon enough to be useful.

## GEOLOGIC AND HYDROLOGIC INVESTIGATIONS IN OTHER COUNTRIES

The U.S. Geological Survey's international program covers a broad spectrum of activities, including participation in international geologic, hydrologic, or topographic conferences and commissions; technical assistance to less developed countries; scientific exchange and cooperative research; and training of earth scientists from other countries. This program results not only from host country requests for technical assistance in developing their earth-science institutions and investigating their natural resources, but also from the need for cooperative research with earth scientists in other countries on geologic or related problems that are important to the United States. To meet these needs, the Geological Survey has provided earth-science specialists for about 1,000 assignments in more than 70 countries during the past 30 years.

During calendar year 1969 the U.S. Geological Survey conducted long-range technical assistance programs in 12 countries in South America, Africa, Asia, and the Far East, and undertook shorter-range programs in 5 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 17 employees on detail to international organizations under authority of the Federal Employees International Organization Service Act (P.L. 85-795, as amended). Individual technical assistance programs vary widely, depending on the host country's stage of economic development, capability of indigenous earth scientists and technical personnel, and viability of earth-science institutions. Some of the major long-range cooperative programs now underway are described briefly here to illustrate the variety and complexity of Geological Survey involvement.

The longest and most continuous of the Geological Survey's cooperative programs began about 30 years ago in Brazil. This program illustrates the range of Survey assistance that may contribute to the needs of the host country. The earliest cooperative studies, during World War II, consisted of strategic and critical minerals investigations, followed in turn by major resource studies of ferrous minerals, base metals,

and uranium minerals. From 1958 to 1965, the cooperative program included assistance in establishing geological curriculums and faculties in several Brazilian universities. During the past decade, with larger numbers of indigenous scientists coming out of Brazilian schools, the program evolved into guidance in conducting geologic mapping and resources studies in several of the more promising districts and in developing the staff and procedures for agencies of the Government of Brazil charged with the responsibility for this work. In recent years, cooperative mineral investigations have been underway in four major districts. Cooperative ground-water investigations were undertaken in six basin areas in the critically drought-plagued northeast region of Brazil; subsequent assistance has been provided in conducting national water-resources investigations.

In Saudi Arabia the Geological Survey's cooperative program has progressed over more than a quarter century from hydrologic studies to reconnaissance geographic and geologic mapping, followed in sequence by regional mineral reconnaissance, evaluation of selected mineralized areas, and quadrangle geologic mapping. Present activities include systematic mapping and resource appraisal in selected districts defined by previous reconnaissance mapping, utilizing geophysics, geochemistry, and analytical and computer support. Topographic and orthophotomapping support a detailed study and appraisal of a potential phosphate area. In addition to obtaining data for development of known resources, basic information on the geologic history and tectonic elements of the Arabian Peninsula is being gathered and interpreted as a guide to the search for additional mineral deposits.

The Geological Survey's long-range program with the Liberian Bureau of Natural Resources and Surveys includes the development of a geological staff and facilities, compilation of reconnaissance geologic and shaded-relief topographic maps of the country, and preliminary appraisal of mineral resources. As geophysical surveys have been found to be a very effective means of gathering data in the deeply weathered tropical terrain, magnetic, radioactivity, and gravity maps constitute important products of the program. The training of indigenous earth scientists

is carried on in Liberia during the course of the work and through academic grants for Liberian students at colleges and universities in the United States.

In Pakistan the Geological Survey has conducted cooperative resources programs since 1953. A major part of this effort has involved hydrologic studies to help reduce waterlogging and salinity in the Indus Valley which have resulted in the identification of techniques now being successfully applied to correct these conditions. A major 14-year cooperative program with the Geological Survey of Pakistan has resulted in a 6-fold expansion of that agency, the preparation of a new geologic map of Pakistan, and the identification of a number of important mineral districts or deposits. Recent studies have been involved mainly with chromite, base metals, and construction materials.

Other long-range programs are currently underway in Colombia, Ethiopia, Indonesia, Kenya, Korea, Nepal, Turkey, and Zambia.

In all the Geological Survey cooperative programs abroad, publication of the results of the investigations is a primary goal. Many of these are written by host-country scientists and published directly by host-country agencies. Since the beginning of the Survey's international program in 1940, more than 1,241 technical and administrative documents authored by Survey personnel have been issued. During calendar year 1969, 80 reports were published and (or) released in open file, and 73 technical administrative documents were prepared (table 2).

As an integral part of the technical assistance programs abroad, 133 earth scientists and engineers from 30 countries pursued academic or intern training in the United States under Geological Survey guidance during fiscal year 1970. Types of assistance given each

TABLE 2.—*Technical and administrative documents issued in calendar year 1969 as a result of the U.S. Geological Survey technical assistance program*

Country or region	Reports or maps prepared			
	Project and administrative reports	Reports approved for publication by the U.S. Geological Survey and counterpart agencies	Reports published in technical journals	Reports published or released by the U.S. Geological Survey
Afghanistan.....	1	1		
Bolivia.....			1	1
Brazil.....	2	10	5	3
Chile.....		1	1	2
Colombia.....	6	8	3	1
Costa Rica.....			1	1
CENTO countries....	1			
Ecuador.....	1			
Ethiopia.....	1			
El Salvador.....	1			
Ghana.....		1		
Guyana.....	2	3	1	2
India.....	2			
Indonesia.....	2			
Iran.....	1			
Jordan.....	1			
Kenya.....	2			
Korea.....	2	1		2
Libya.....		1	1	
Liberia.....	20	12	9	7
Middle East.....	1			
Nepal.....				1
Nigeria.....		2		
Pakistan.....	8		1	1
Peru.....				1
Philippines.....	1	1		1
Saudi Arabia.....	6	11	6	25
South and Central America.....		1		
Thailand.....	2		1	1
Turkey.....	4		1	
General.....	6	3		
Total.....	73	56	31	49

country during the fiscal year are summarized in table 3. To date, 1,071 participants from 78 countries have completed academic or intern training in the United States under Survey guidance.

TABLE 3.—*Technical assistance to other countries provided by the U.S. Geological Survey during fiscal year 1970*

Country	USGS specialists assigned to other countries			Scientists from other countries trained in the United States	
	Number	Type	Type of activity <sup>1</sup>	Number	Field of training
<b>Latin America</b>					
Argentina.....	2	Hydrologist.....	D.....	1	Radioactive materials.
Brazil.....	15	Geologist.....	A.....	14	Geologic administration.
	6	Hydrologist.....	A.....	3	Aerial photography.
	1	Civil engineer.....	A.....	1	Economic geology; photogeology.
	1	Mining engineer.....	A.....	3	Photogrammetry.
	1	Metallurgist.....	A.....	1	Map making and photogrammetry.
	1	Public utility specialist.....	A.....	1	Geology.
				3	Chemistry.
				3	Ultramafic rocks.
				2	Exploration geology; geochemistry.
				1	Computer studies.
				1	Scribing, drafting, printing, and so forth, for technical illustrations and map publication.
				1	Exploration techniques; economic geology.
				1	Geochemistry.
				2	Surface water hydrology.
				1	Ground water; geophysics; computers.
				1	Ground water.
				1	Economic geology.
				4	Radioactive materials.
Chile.....	2	Hydrologist.....	D.....	1	Engineering geology.
	1	Hydraulic engineer.....	D.....	2	Mining geology.
Colombia.....	8	Geologist.....	B.....	1	Inorganic chemistry.
	1	Chemist.....	B.....		
	2	Driller.....	B.....		
El Salvador.....				1	Geochemistry in geothermal exploration.
Guyana.....				1	Geodetic surveying.
				1	Hydrology.
				1	Alluvial mineral technology.
Venezuela.....				1	Hydrology.
<b>Africa</b>					
Egypt.....				1	Geochemistry.
Ethiopia.....	1	Hydrologist.....	D.....	1	Hydrology; management engineering.
	1	Cartographer.....	D.....		
	1	Librarian.....	D.....		
Ghana.....				1	Hydrology; geophysics.
Kenya.....	1	Hydrologist.....	C.....		
Liberia.....	1	Geologist.....	A.....	3	Geology.
	1	Geophysicist.....	A.....		
	1	Cartographer.....	A.....		
	1	Secretary.....	A.....		
	1	Administrative officer.....	A.....		
Morocco.....				1	Potash.
Nigeria.....				1	Analytical techniques.
Somali.....				1	Geology, geochemistry, geophysics.
South Africa.....				1	Microprobe analysis.
Sudan.....				2	Hydrometeorology.
Zambia.....	1	Hydrologist.....	C.....		
<b>Near East-South Asia</b>					
Afghanistan.....	1	Hydrologist.....	D.....	1	Topographic mapping.
				2	Hydrogeology.
				1	Hydrology.
India.....	1	Geologist.....	C.....	3	Drilling techniques.
				2	Ground water hydrology.
				1	Surveying and mapping.
				1	Mineral exploration.
				1	Ground-water development.
Iran.....	1	Geologist.....	D.....		
Jordan.....				1	Hydrology; ground-water.
				2	Hydrology.
				2	Engineering geology.
				1	Ground-water investigations and development.
				1	Ground-water geology.

See footnote at end of table.

TABLE 3.—*Technical assistance to other countries provided by the U.S. Geological Survey during fiscal year 1970—Continued*

Country	USGS specialists assigned to other countries			Scientists from other countries trained in the United States	
	Number	Type	Type of activity <sup>1</sup>	Number	Field of training
<b>Near East-South Asia—Continued</b>					
Nepal.....	2	Hydrologist.....	C.....		
Pakistan.....	2	Geologist.....	A.....	1	Ground-water hydrology.
	5	Hydrologist.....	A.....	1	Geology of aluminous materials.
				3	Hydrology.
				1	Mineralogy, petrography, and laboratory techniques.
				1	Phosphatic minerals.
				1	Technical management of water-resources projects.
				1	Hydrology, computer techniques.
				3	Hydrologic monitoring and research techniques.
Saudi Arabia.....	16	Geologist.....	A.....	7	Geology.
	3	Geophysicist.....	A.....	1	Report composition.
	3	Driller.....	A.....		
	1	Administrative officer.....	A.....		
	1	General services officer.....	A.....		
	1	Procurement and shipping assistant.....	A.....		
	4	Cartographer.....	A.....		
	1	Chemist.....	A.....		
	1	Electronic technician.....	A.....		
	3	Civil engineers (technical).....	A.....		
	1	Mathematician.....	A.....		
	1	Publications specialist.....	A.....		
Turkey.....	10	Geologist.....	B.....	2	X-ray fluorescence.
	1	Driller.....	B.....	1	Spectroscopy.
	1	Metallurgist.....	B.....	1	Geologic administration.
				3	Drilling.
				1	Publication preparation and reproduction.
				1	Management of mineral exploration projects.
<b>Far East</b>					
Ceylon.....	1	Geologist.....	D.....		
Indonesia.....	5	Geologist.....	A.....	2	Minerals development.
	1	Cartographer.....	A.....	1	Hydrology.
				1	Marine geology.
				1	Chemistry of radioactive materials.
Korea.....	1	Hydrologist.....	C.....	1	Cartography, mapping, and map reproduction.
				1	Economic geology.
				1	Ground-water development.
				1	Geochronology.
				2	Water-resources management.
Laos.....	1	Hydrologist.....	D.....		
Republic of China.....				1	Analytical techniques.
Thailand.....	1	Geologist.....	D.....		
	1	Hydrologist.....	C.....		
Vietnam.....				1	Surface-water techniques.
<b>Other</b>					
Australia.....	2	Hydrologist.....	D.....		
France.....				1	Isotope geology laboratory techniques.
Germany.....				1	Seismic crustal studies.
Italy.....				1	Earthquake research.
				1	Volcanology.
Poland.....				1	Hydrochemical research.
				1	Hydrology.

<sup>1</sup> 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

### AFGHANISTAN

#### Hydrographic and sedimentation survey of Kajakai Reservoir

D. C. Perkins and J. K. Culbertson,<sup>111</sup> using underwater mapping techniques, completed a detailed hydrographic and sedimentation survey of Kajakai Reservoir on the Helmand River in central Afghanistan in late 1968. They found that the reservoir had lost a net 7.0 percent or 104,800 acre-ft of its initial storage capacity since the beginning of operation in 1953, owing to sediment deposition and an average annual rate of sedimentation in this period of 7,800 acre-ft.

### BRAZIL

#### Mineral investigations

U.S. Geological Survey (USGS) geologic and mineral investigations continued in cooperation with the Departamento Nacional da Produção Mineral (DNPM). In Bahia (locality 1, index map), G. H. Goudarzi (USGS) working with others from the DNPM found that the Pedras Altas apatite-bearing zone extends to the north of the Itapicurú River. Near Apolonária they found large crystals of apatite in a zone of vermiculite and biotite associated with syenitic pegmatites. The vermiculite is being mined, and in several pits the apatite and vermiculite are exposed over an area of several hundreds of square meters. In other areas apatite is associated with syenitic pegmatite or with clinopyroxene. Spectroscopic study and X-ray analysis by J. B. Cathcart on samples from the area indicates that the apatite contains rare earths.

The Goiás (loc. 2) serpentine belt has been under study since 1967. Fieldwork by geologists of DNPM assisted by C. L. Hummel, R. W. White, and D. B. Hoover resulted in further identification of mineral possibilities in the ultramafic and associated rocks. The project area has been enlarged to about 500,000 km<sup>2</sup> because the area with economic potential is greater than previously realized. Three of the principal ultramafic bodies being mapped in detail are Niquelândia, Barro Alto, and Juçara. In late 1969, T. P. Thayer made a brief appraisal of the overall economic potential of peridotites and related rocks in Bahia and Goiás. He considers the principal resources in Goiás to be garnierite and lateritic nickel deposits, asbestos, high-alumina chromite, possibly platinum, talc, bauxite, and construction materials.

<sup>111</sup> Perkins, D. C. and Culbertson, J. K., 1968, Hydrographic and sedimentation survey of Kajakai Reservoir, Afghanistan: U.S. Geol. Survey open-file report, 87 p., 36 figs.



Investigations of chromite deposits, by DNPM geologists with the assistance of D. C. Hedlund, continued near Campo Formoso in the State of Bahia. Work to date, which includes a short-term advisory study by T. P. Thayer, indicates the chromitite layers in partly serpentinized ultramafic rocks are of stratiform origin and appear to dip to the east under the Serra de Jacobina. Preliminary geophysical surveying in the area seems to confirm this indication. Of particular significance is the finding of geophysical anomalies over an extensive area east of the Serra de Jacobina where a recently opened chromite deposit examined by D. B. Hoover and associates of DNPM, also appears to be stratiform.

The Brejuí mine (loc. 3), in the State of Rio Grande do Norte, the principal producer of tungsten in the northeast Brazil tungsten district, has been studied in detail by R. H. Nagell (USGS) and counterparts in DNPM. The ore is found in folded tactite and marble inclusions in the Acará Granite which are a part of the Precambrian Ceará Series. Data from these investigations are being used by the DNPM to assist the mine operators in planning mine development and increasing operating efficiency. Interest in this project, combined with the rising price of tungsten in world markets, stimulated considerable local activity in search of scheelite deposits.

R. J. Hite has reported on data obtained by DNPM during recent exploration in coastal basins in the State of Sergipe (loc. 4), which have outlined a new potential source of magnesium. Tachydrite ( $2\text{MgCl}_2 \cdot \text{CaCl}_2 \cdot 12\text{H}_2\text{O}$ ) forms an enormous deposit associated with other evaporites in the Cretaceous

Muribeca Formation. The deposit consists of two zones separated by a thin deposit of halite and carnallite. Locally the upper zone is more than 100 m thick and is almost pure. In terms of evaporite geology, the deposit is very unusual. Normally tachydrite occurs only as a rare accessory mineral associated with potash deposits. Because it is extremely soluble (2.5 times as soluble as carnallite), tachydrite represents an extreme phase of concentration of sea water. The upper zone of the deposit contains at least 4 billion metric tons of tachydrite. This represents about 1.47 billion metric tons of  $MgCl_2$  or 380 million tons of magnesium metal. At present-day consumption, this represents about a 2,000-year supply for the world. At current metal prices, the in-place value of the upper zone of the deposit, assuming a 30-percent recovery, is about \$68 billion. The high solubility, great thickness, and purity of the deposit would seem to provide conditions favorable for recovery by solution mining. Although the technology of magnesium metal production from tachydrite has not been worked out in detail, it is possible that it can favorably compete with the sea-water process.

Phosphate investigations continued in the Cedro do Abaete-Quartel São Joao area of Minas Gerais, where deposits of phosphorite with as much as 35 percent  $P_2O_5$  are found in late Precambrian siltstones of the Bambui Group, known to be underlain by phosphatic beds. J. W. Mytton (USGS) and Fernando de Oliveira (DNPM) completed geologic mapping of two areas north of the Quartel São Joao high-grade deposit. Regional geochemical methods, beneficiation, and utilization tests are being made.

Geologists of the DNPM, with some guidance from J. D. Friedman and other U.S. Geological Survey personnel, investigated the use of remote sensors in parts of the Quadrilátero Ferrífero under a cooperative United States-Brazil research program on application of remote sensors to resource studies. The remote sensor surveys were made in 1969 by the National Aeronautics and Space Administration in cooperation with the Comissão Nacional de Administração Espacial. Thermal infrared imagery, side-looking radar imagery, and several aerographic film types were tested over zones of deep residual soils and hematite-bearing itabirite formation.

Preliminary analysis of the infrared imagery suggests that thermal infrared data can be used to differentiate several iron-bearing units from residual materials on the basis of thermal-inertia distinctions affecting the diurnal temperature curve. Of several film types tested in this tropical environment, Ekta-

chrome infrared 9×9-inch format (type SO-246 exposed through an 89B filter) at 5,000- and 21,000-foot altitudes proved to be most useful for distinguishing residual soil, laterite, and vegetation color variations related to underlying bedrock.

## CHILE

### Nonmetals investigations

J. J. Norton made a 4-month study of nonmetallic mineral resources of the Department of Arica, Chile, at the request of, and in cooperation with, the Instituto Investigaciones Geológicas of the Government of Chile, in order to identify the problems attendant on wider use of domestic raw materials as Chile's economy expands. Results of the study can be applied to much of northern Chile. Geologic exploration for nonmetals probably will yield economically useful results if attention is directed to saline deposits, dolomite, diatomite, phosphate, and high-quality clays. Of these, salines and diatomite exist in large amounts, and clays are seemingly sparse.

### National hydrologic data system

According to W. W. Doyel and M. E. Moss the major drought of 1967-69 in central Chile brought into sharp focus the lack of adequate data on water resources and the lack of a system for centralizing and analysing available hydrologic data in Chile. In their report of November 1969 (Doyel and Moss, r2570) based on a 3-month tour in Chile they outline in detail some 19 recommendations for implementing a national hydrologic data system that include control, organization, charter, training, information catalog, standards work groups and others.

### Systems analysis of water resources in Rio Aconcagua valley

As a consequence of the severe and prolonged drought in 1967-69 in central Chile, the Government of Chile has directed its efforts toward the development and management of the water resources in the region. In October-December 1969, J. E. Moore made a 2-months study of the Rio Aconcagua valley to design a prototype water-resources-systems investigation including digital computer modeling, the results of which would have general application in most of the larger river valleys of central Chile. His report of December 1969 (Moore, r2575) described the general hydrogeology and hydrology of the Rio Aconcagua basin and the present status of water-resources investigation and development, and he enumerated the additional data requirements for systems analysis.



## COLOMBIA

### Base-metal studies

Selected zinc-lead mines and prospects in Lower Cretaceous rocks in the Cordillera Oriental were briefly examined by Helmuth Wedow, Jr., and R. B. Hall and Colombian counterparts of the Instituto Nacional de Investigaciones Geológico-Minero (Ingeominas). The deposits seem to be controlled by fractures almost normal to bedding at El Veleno, La Amarilla, El Escobal, San Rafael, and Cueva Oscura, but by fractures parallel to bedding at Coromoro, Montenegro, and El Rincón. The La Playa deposit, near El Rincón, is a sphalerite-bearing colluvial placer, but it probably derives from bedrock deposits similar to El Rincón. All the localities show slickensides and evidence of postmineralization structural disturbance, but obvious alteration halos, typical of the base-metal deposits of the Western United States, were not observed.

Although no obvious similarities between these deposits and stratabound zinc-lead deposits in the United States were observed, early solution-collapse porosity probably exists where evaporites and some limestone are interbedded with less soluble strata. One of the better possibilities for this is in the halite-shale-sandstone sequences of the Lower Cretaceous in the vicinity of Gachetá; there and at El Rincón and other deposits, "bedding breccias and veins" with massive sphalerite are known over a strike length of about 15 km. Breccia textures resemble some stratabound solution-collapse breccias. D. H. McLaughlin, Jr., found sphalerite at the same stratigraphic position as a number of small halite or other evaporite bodies.

### Phosphate investigations

Detailed mapping of Lower Cretaceous phosphate deposits containing 15 to 25 percent  $P_2O_5$  has resulted in finding large new reserves in the sandy, shoreline facies of the miogeosyncline. This ore type does not contain free lime and is much more susceptible to beneficiation than the high-lime ore. As much as several hundred million tons of carbonate-free rock phosphate may be present. J. B. Cathcart and counterparts from Ingeominas are continuing the phosphate study.

### Pisolitic iron deposits

Pisolitic bedded iron ore in upper Tertiary beds was discovered by Ricardo Camacho (Ingeominas) and others while mapping in the Sabana Larga area along the eastern foothills of the Eastern Cordillera. The deposits may have economic significance because the presently exploited iron ore deposit at Paz del

Rio, which forms the basis for Colombia's only integrated steel plant, apparently has approached its maximum level of development. No analyses are available as yet.

### Geochemical studies

Near Salento, in the Central Cordillera, a vein of silver-bearing galena has been traced for 800 meters by Dario Barrero (Ingeominas) and others. Geochemical studies of the surrounding area are being made in the hope of finding additional veins.

## INDIA

The U.S. Geological Survey's phosphate investigations program in India was terminated with the return of S. A. Stanin to the United States. Most of the phosphate prospects in the Mussoorie area, Uttah Pradesh, are submarginal. Only the deposits at Maldeota and Durmala, having a combined total of 10 million tons of inferred reserves, could be successfully beneficiated to specification grade and are regarded as possibly marginal. Factors unfavorable to development are: terrain is rugged and transportation facilities are very poor; the low-grade, impure carbonate-phosphate rock requires beneficiation; the beds are thin, variable in composition, and strongly folded and faulted; available tonnage is relatively small; and mining would have to be done by underground methods and would be expensive. Whether or not these deposits can be ultimately developed by the Government of India will depend on the economics of mining, transportation, and beneficiation. The interest stimulated in establishing this project in India, however, gave impetus to the Geological Survey of India and the State of Rajasthan Directorate of Mines and Geology to undertake independent phosphate investigations in other parts of the country. These efforts resulted in the discovery of large potential reserves of phosphorite near Udaipur, Rajasthan.

## IRAN

### Playa research

D. B. Krinsley spent three summers investigating playas in Iran under the sponsorship of the U.S. Air Force Cambridge Research Laboratories. His research led him to the following conclusions: The areal distribution and individual development of lacustrine features in the mountains and more interior basins of Iran suggest that the Pleistocene climatic patterns were similar to those of the present, but were periodically intensified during cold phases of that epoch. The former presence of shallow lakes suggests increased runoff

due to temperature depression rather than to significantly increased precipitation. According to information from the National Iranian Oil Co., the stratigraphic section of a large playa in the northern interior of Iran contains five layers of alternating mud and salt which extend to a depth of 46 m. The extent and composition of these sediments argues for alternating humid (mud) and arid (salt) climates during the Pleistocene. The central part of the Iranian interior probably was an area of generally prevalent aridity during the Pleistocene, as evinced by yardangs (irregular ridges, usually found alternating with round-bottomed troughs, formed by eolian erosion) as much as 60 m in local relief.

### KOREA

#### Native copper deposits

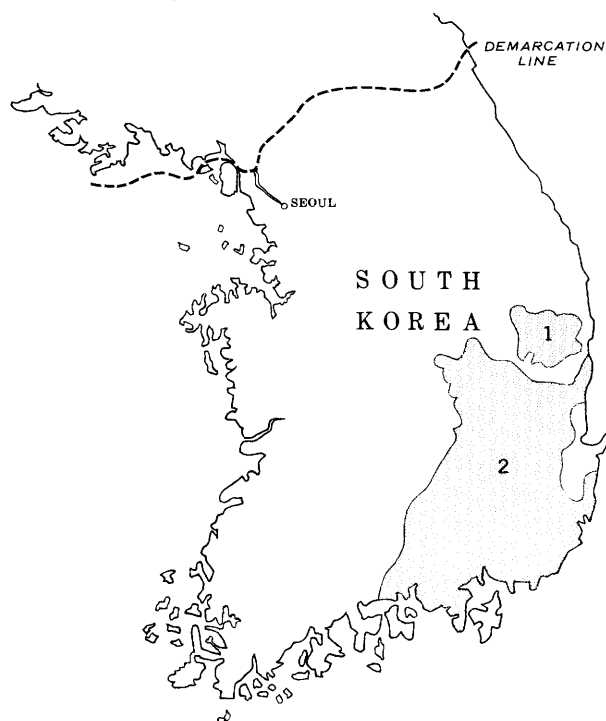
Native copper in Cretaceous basalt in the Yongyang Basin (locality 1, index map) and Kvongsang Pukto (loc. 2), was studied by W. S. White in April and May 1969. The native copper was discovered by J. H. Lee, now Director of the Geological Survey of Korea, in 1963, and that organization has explored the area in which the copper occurs by trenching and, in 1969, by diamond drilling. The geologic setting resembles that of the native-copper deposits of northern Michigan in the following respects: (1) red nonmarine clastic sedimentary rocks are interstratified with a thick sequence of slightly metamorphosed flood basalts, (2) all the types of flow tops recognized in Michigan are

present in the Yongyang Basin, and (3) the basalts and associated rocks occupy a well-defined structural basin in which the rocks dip gently over large areas. The geologic setting differs from that of the Michigan deposits in the following respects: (1) the sedimentary rocks are finer grained, and even the conglomerates and coarse sandstones contain more interstitial silt and clay; (2) the lava flows and their amygdaloidal tops are thinner, and the interstices of the fragmental tops are largely choked with fine-grained detrital material; (3) the thickness and maximum depth of burial of rocks in the Yongyang Basin are much less than in Michigan, and dips exceeding  $30^\circ$  are rare; and (4) the rocks of the Yongyang Basin do not appear, generally, to have reached the prehnite-pumpellyite facies of metamorphism to which the principal copper-bearing rocks of Michigan belong. The native copper itself is disseminated throughout the massive basalt of the two lava flows in the area of interest, in marked contrast to its concentration in flow tops in the Michigan deposits. Though significantly lower than those of Michigan, the concentrations of copper are definitely anomalous; the best 2 m in some drill holes contains as much as 0.22 percent copper, and the average for the entire thickness of both flows is locally as much as 600 ppm—quite enough to warrant the explorations that have been undertaken. The absence of many of the geologic conditions that seem to characterize the Michigan copper deposits—permeable host rocks, steep dips, a very large and deep basin, and a higher metamorphic grade than that at Yongyang—makes it unlikely that deposits comparable to those of Michigan occur in the Yongyang Basin. On the basis of limited assay data available at the time of this study, the amount of copper in the lower flow appears to vary directly with that in the upper flow, suggesting that the copper is epigenetic. On the other hand, the lack of obvious permeability or structural control and the dissemination of the copper, particularly in the massive basalt, could be taken as evidence that the copper is a primary constituent of the flows.

### LIBERIA

#### Heavy-mineral studies

In the cooperative Geologic Exploration and Resources Appraisal Program (GERA) with the Liberian Geological Survey (LGS), Samuel Rosenblum (USGS) and S. P. Srivastava (LGS) used heavy-mineral analysis to determine mineral provinces. Study of more than 1,800 samples indicates that 5 mineral provinces can be recognized in the total assemblage of 41 mineral species, as follows: (1) sillimanite-kyanite-



staurolite-monazite-gold-corundum, (2) monazite-rutile-gold-xenotime, (3) monazite, (4) magnetite-chromite-monazite-xenotime, and (5) cassiterite-columbite. The cassiterite-columbite samples are from the St. John River area, which is part of a former exploration concession where company geologists had reported detecting tin and niobium in spectrographic tests of heavy-mineral concentrates.

#### Economic mineral products

Silica sand in thin surficial deposits covers much of the coastal area between Monrovia (locality 1, index map) and Buchanan (loc. 2). Samuel Rosenblum and S. P. Srivastava found that the sand is of good quality for glass manufacture, and estimated that more than 100 million metric tons is easily accessible near Monrovia. Beach sand from the Harper area (loc. 3) was found by Srivastava and Rosenblum to contain sufficient shell material to be a source of industrial calcium carbonate. The shell sands are locally abundant and could supply much needed lime by operations similar to those in the Gulf of Mexico. Phosphate minerals in earth materials probably derived from bat guano have been studied by the same team, supplemented by X-ray tests by Charles Milton. If the material can be used with little treatment, it may constitute a supply of fertilizer for local use. Building stone in polished slabs is being tested by Rosenblum for weathering characteristics; if the tests are favorable, quarries could be established at various localities where hard unweathered rock is at or near the surface.

L. V. Blade (r0886) found the Bushrod Island-New Georgia clay deposit (vicinity of loc. 1) to be composed of weathered clay and fine quartz sand in channel fillings in a former delta of the St. Paul River. On the basis of differing iron content, three units are distinguished. Potential indicated reserves are estimated as 1,800,000 tons (iron rich); 5,300,000 tons (low iron); 470,000 tons (high iron). The clay is suitable for manufacture of brick, hollow tile, drain tile, roofing and

quarry tile, porous earthenware, low to intermediate refractory products, stoneware, and small-diameter sewer pipe.

#### Geophysical investigations

Aeromagnetic and radiometric surveys were completed for the entire country of Liberia, and a gravity survey was made along the road network and coast. The data are being studied by J. C. Behrendt (USGS) and C. S. Woterson (LGS). Three provinces were delineated on the basis of rock age and geophysical data. The Liberian province (2,700–3,400 m.y.) in the northern two-thirds of the country is separated by a major northeast-trending break in the magnetic fabric from the Eburnean (1,800–2,000 m.y.) in the southeast one-third. The Pan-African province (500–600 m.y.) lies along the northwest part of the coast. Ninety kilometers inland a zone of diabase dikes (400 m.y.) can be traced by magnetic data from Sierra Leone to Ivory Coast. A younger zone of dikes (Jurassic, about 185 m.y.) can be traced along the coast and continental shelf northwest of Greenville. Intrusion of these dikes is thought to coincide with the separation of the continents at the south end of the north Atlantic. Magnetic anomalies indicate Cretaceous or younger sedimentary rocks as much as 5 km thick in faulted basins on the continental shelf. These basins, recently inferred (R. W. White, r2585) from the magnetic data, are of considerable interest to petroleum companies because of the potential for oil. Several lines of evidence suggest that underlying Paleozoic(?) rocks are less than 1 km thick.

The following sequence of events is suggested: tectonic activity in the periods 2,700–3,400, 1,800–2,000, and 500–600 m.y. ago; uplift and exposure of deep crustal rocks; deposition of Paleozoic sediments; intrusion of 400-m.y.-old diabase dikes; intrusion of 185-m.y.-old diabase dikes and sills accompanying separation of Africa and South America; block faulting along coast and continental shelf; seafloor spreading, filling of basins in Cretaceous and Tertiary(?) time; basalt extrusion on spreading sea floor; and sedimentation on continental slope.

Aeromagnetic contour maps of the country were digitized on a 1- by 1-minute grid. With the assistance of G. E. Andreasen and P. D. Zabel, a generalized residual magnetic map was contoured (100-gamma interval). This map reveals a number of interesting features not observed in the original data. Long northeast-trending anomalies cross the entire country at amplitudes ranging from 200 to 600 gammas and 60 to 80 km wavelengths. These trends are parallel to the detailed lineations in the northwest (inland) two-thirds



of the country which were previously correlated with the Liberian age province. The broad residual anomalies, however, continue across the coastal area, whereas the pan-African thermotectonic event imposed a northwest-trending grain on the detailed magnetic lineations. In the eastern third of the country, high-amplitude, narrow wavelength (10–15 km), northeast-trending anomalies associated with isoclinally folded paragneisses and schists in the Eburnean age province are superimposed on the broader northeast trends of the older (Liberian age) anomalies. Other investigators have correlated regional northeast-trending anomalies in Ivory Coast and Sierra Leone with similar anomalies in the Guyana shield area of South America. The data fit this picture and help fill a former gap in knowledge of the coastal region of Africa.

Over most of the continental shelf and in the coastal area near Monrovia, the residual magnetic map shows northwest-trending anomalies of about 20-km wavelength and 100- to 200-gamma amplitudes crossing the broader northeast-trending anomalies. These could be a weak effect of the pan-African activity but are more likely associated with the diabase intrusions of 185 m.y. age. The residual magnetics over the continental shelf east of Greenville (loc. 4) are mainly a continuation of the northeast trends of the onshore magnetic data, and the northwest-trending anomalies exist in this area only over the continental slope.

Radiometric data indicate a background level of less than 100 counts per sec (180 counts per sec = 1  $\mu$ r/hr) over mafic granulites and sedimentary rocks of the coastal area. Granitic rocks have the greatest variation, and the central part of the country is substantially higher than the rest. A few specific radiometric anomalies were correlated with concentrations of monazite and zircon, one in an area of black beach sands where samples were collected on beach traverses and by helicopter reconnaissance. Uncommonly high radioactivity values were observed on the ground at Greenville, and further testing of the black sand is in progress. Samuel Rosenblum and S. P. Srivastava also collected rock and soil samples in the Bomi Hills-Bopolu area (loc. 5), where high radioactivity is due to zircon and monazite, both in laminated gneiss and overlying laterite.

#### **Gravity survey of Liberia**

A regional gravity survey is currently in progress covering most of the accessible parts of Liberia. A total of about 1,300 stations were occupied throughout the country on level lines along roads, in the coastal area at sea level, and along some roads where altimetry

was used for elevation control. In general the gravity is high, and the mean free-air anomaly over Liberia is probably in excess of 20 mgal, suggesting a regional isostatic anomaly. The Bouguer anomaly map shows a strong regional linear gradient parallel to the coast where values decrease from +65 to about -10 to +10 mgal inland. A significant part of this anomaly change is the result of rapid crustal thickening at the continental margin. Although analysis is not complete, two-dimensional models of crustal structure based on these data and some U.S. Coast and Geodetic Survey data at sea suggest a steep, possibly faulted transition from oceanic to continental crust (as might be expected in West Africa, which was presumably separated from South America by rifting). The coastal anomaly gradient exceeds 4 mgal/km over the western part of the country which indicates that crustal thickening would be insufficient to entirely explain the gradient. The probable cause is the transition from mafic granulite facies rocks to granite gneisses in this area. The mean density of the surface rocks in Liberia probably exceeds 2.7 to 2.8 g/cm<sup>3</sup> which indicates a quite high mean crustal density. Local features of the gravity field include -25 mgal anomalies over Cretaceous sandstones in basins onshore and anomalies below -50 mgal over basins in the continental shelf. Positive anomalies in excess of 30 mgal exist over at least two known mafic intrusive bodies (with associated -2000-gamma magnetic anomalies), one of which contains indications of cobalt and nickel.

## **NEPAL**

### **Hydrology and water-resources development**

In calling attention to the importance of hydrology in the development of the water resources of Nepal, W. W. Evett (r2571) pointed out that annual runoff is more than adequate to meet existing and foreseeable needs for basic water supply, and that a large potential exists for hydropower and irrigation development from Nepalese rivers. There is, however, a wide range in the annual flow regimens of all rivers with flooding common in the monsoon season (June to September) and deficient flow in the late dry season (March to June). In the near future because of economic constraints, most hydropower will be obtained from run-of-the-river installations, and most irrigation water requirements will be met from tubewells and low-lift pumping stations along the larger perennial streams in the Terai Belt and from canal diversions of tributaries to irrigable bench lands and terraces in the Midlands region.

## PAKISTAN

### Chromite investigations in the Hindubagh district

Most of the chromite mining district near Hindubagh (locality 1, index map), in the Zhob Valley about 75 miles northeast of Quetta, has been mapped in detail by D. L. Rossman (USGS) and Zaki Ahmad, Gasanfur Abbas, and M. H. Rahman, Geological Survey of Pakistan (GSP), to establish the relation of chromite deposits to the ultramafic country rocks.

The Jung Tor Ghar (range) at the western end of the Hindubagh district is an ultramafic block that may have been thrust over Triassic to Cretaceous sedimentary rocks; the Saplai Tor Ghar-Nasai block to the east is a similar but larger mass. Both blocks are similar in general composition and distribution of internal rock types; originally both were probably parts of a single mass. Eocene sedimentary rocks were deposited over the ultramafic complex.

The ultramafic rock is made up of olivine and varying amounts of orthorhombic pyroxene, and magnesium-rich diopside. The parts low in pyroxene were mapped as dunite, whereas the part richer in pyroxene was mapped as harzburgite. Boundaries between the harzburgite and dunite are gradational; in places several intermediate phases are present and could be mapped separately. A reasonably consistent north-striking and east-dipping compositional layering formed by the presence of distinct layers of varying proportions of pyroxene to olivine is present in the Jung Tor Ghar. Similar layering in the Saplai Tor Ghar also generally dips eastward but locally forms a large north-plunging syncline whose eastern limb is partly overturned toward the east. Because of the general eastward dip in compositional layering, progressively higher sequences are exposed eastward in both

the Jung Tor Ghar and Saplai Tor Ghar-Nasai blocks. In the Saplai Tor Ghar-Nasai block, a thick dunitic unit lies above the harzburgitic rock, which is followed by pyroxenite (websterite) and then by mafic gabbro. Light-colored dioritic rock is present in the central part of the gabbroic mass.

In both the Jung Tor Ghar and Saplai Tor Ghar areas dunite also extends irregularly across the compositional layering in many places, forming transgressive dunite. The layered structure tends to persist through the transgressive dunite without discernible deviation. This is evinced in the dunite by darker zones composed of some altered pyroxene and by the tendency for the pyroxene and accessory chromite to be aligned with their long axis parallel to the layering plane. The transgressive dunite probably does not represent a separate intrusive magmatic phase, nor is there evidence that it is intruded or injected into the pyroxene-richer part. In a few places some dunite may be intrusive. The transgressive dunite is most abundant on the west side, near the base, of the two ultramafic blocks and there makes up 50 to 80 percent of the total rock. It is less abundant upward (eastward) and is absent in the structurally highest parts of both blocks, which are several thousand feet stratigraphically above the base.

The transgressive dunite masses are of all shapes and sizes. Some are very irregular and show no controls with respect to shape or relation to surrounding rocks or layering, but most masses tend to preferentially extend into the pyroxene-lean parts of the enclosing layered harzburgite. In places, masses of transgressive dunite extend thousands of feet away from the main mass, which may be several hundred feet across. These may preferentially follow a favored layered horizon, then break away for a distance, and thence back again. In other places the transgressive dunite may form linear masses through which the regional layered structure passes. In the higher parts of Saplai Tor Ghar where the transgressive dunite is less abundant, it may form steeply dipping pipe-shaped masses through which the layered structure passes. Some pipes contain a central core of chromite, preferentially present as layers parallel to those in the enclosing rock.

Probably more than 1,000 chromite prospects and small mines are present in the Jung Tor Ghar, and a greater number are present in the Saplai Tor Ghar-Nasai areas. Almost all the chromite is associated with the transgressive dunite in the Saplai Tor Ghar, generally at the structural tops of the masses. It appears to be centrally located in the pipe-shaped masses, but



the individual chromite masses tend to be disposed as layers parallel to the regional layered structure. In the Nasai area, where the ultramafic rock is largely pyroxene free, the chromite forms layers parallel to the regional layering but tends to be disseminated and richer in iron than that associated with transgressive dunite.

Recognition of the fact that there may be preferential location of the chromite deposits at or near the tops of the transgressive dunite masses should be helpful in systematic exploration for chromite.

#### **Primary layering in alpine-type ultramafic rocks**

Investigations by D. L. Rossman (USGS) and Gasanfur Abbas (GSP) reveal extensive chromite-bearing layers in near-horizontal zones in a typical alpine-type ultramafic complex at Dargai (loc. 2). The complex, which is probably a fault block thrust over and into schists of Precambrian age, is about 16 miles long and  $3\frac{1}{2}$  miles wide. Scattered masses of gabbro crop out along the north side. Most of the chromite forms thin, highly disseminated chromite-bearing layers that crop out discontinuously for several miles. The strong regional compositional layering in the ultramafic rocks is believed to have formed by tectonic movement; it forms a near-vertical homocline striking parallel to the long direction of the complex. Some of the chromite layers also dip steeply, but detailed work shows that they may be at any angle to the tectonically derived layering. Extensive flat chromite-bearing layered zones are also present, and a parallel compositional layering is vaguely, but definitely, present for about 1,000 feet above the subhorizontal chromite zone. The uniform and extensive flat-layered zone and the conformable underlying chromite layer suggest that the complex still retains visible evidence of primary layering. Primary layers are rarely found in alpine-type complexes, and few good criteria are available to distinguish between the two. Cumulate textures, generally regarded as evidence of primary origin, have not been found, but there is some evidence that recrystallization has taken place.

#### **Tarbela dam site**

Drilling at the site selected for the Tarbela dam on the Indus River (loc. 3) has revealed a 643-foot buried vertical cliff in the bedrock profile under the alluvium. The area was studied earlier by J. A. Calkins and Pakistan geologists who postulated a left-lateral reverse fault beneath the damsite and paralleling the river. Rock types penetrated in the drilling show that the base of the dropoff marks the location of the fault.

Although fault related, the precise origin of the cliff

is problematical; it may represent an original fault scarp or it may be a result of river scour along the shear zone. A mechanism based on the analogy of Boulder Dam has been suggested, involving deep scour during superfloods followed by instant backfill, whereby such a cliff would be preserved from both river and subaerial erosion. Surface information indicates an inactive fault.

#### **Structural studies**

Fieldwork in Chitral was completed in mid-1969 by J. A. Calkins and counterparts of the Geological Survey of Pakistan. Presently accepted interpretations have been based upon reconnaissance work done in the Reshun area, 40 miles upriver from Chitral (loc. 4), where conspicuous faults exist between the Chitral Slate belt and the Cretaceous rocks on either side. Southwestward in the Chitral area, however, these faults fade out, and the central slate belt is in gradational contact with the adjacent Cretaceous rocks.

Regionally the area consists of a wide belt 100 miles long of lower Paleozoic Chitral Slate, bounded on both sides by narrow bands of Cretaceous rocks followed by Paleozoic limestones. Thus previous interpretations require that two thin units of Cretaceous rocks 100 miles in length be downfaulted between Paleozoic rocks.

As newly interpreted, the Chitral Slate is of younger Cretaceous age and forms the trough of a syncline of regional extent. As no fossils have been found in the Chitral Slate, however, these new conclusions cannot be considered final.

### **SAUDI ARABIA**

The present cooperative program of investigations in Saudi Arabia, started in 1963 on behalf of the Ministry of Petroleum and Mineral Resources, was extended another 3 years from September 1969 to September 1972. During the new phase of the program, emphasis will be on geologic mapping and appraisal of mineral resources in selected districts covering about 28,000 sq mi of Precambrian rocks, studies of the application of aeroradiometric mapping techniques to geologic mapping problems, processing and interpretation of geophysical and geochemical data, and marine geologic studies in the Red Sea. Some of the more significant results of recent work under this program are given below.

#### **Geophysical studies**

An airborne digital gamma-ray spectrometer system has been installed in a Beaver aircraft for systematic low-level surveys of pediment and other areas within the U.S. Geological Survey mapping districts. A sys-

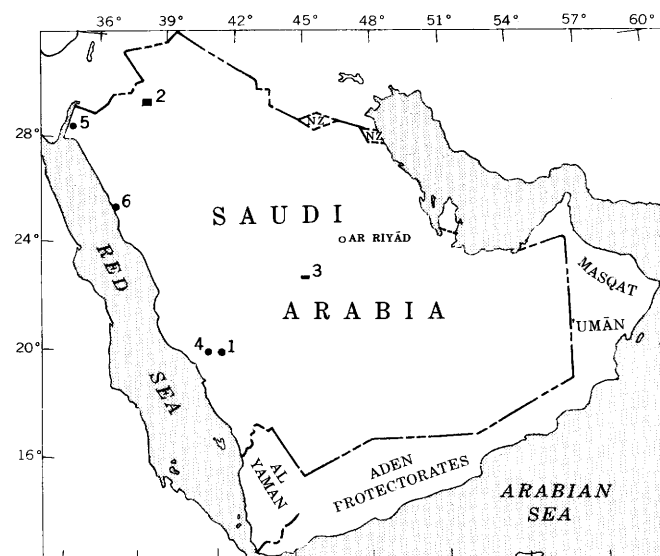
tem of computer programs has been developed for rapid processing of the field tapes leading to automated plotting of nested radiation profiles for all four channels (uranium, potassium, thorium, and gross), plus ratios. The automatic data plotter will also provide contour maps for any or all channels of information. The principal value of the system lies in its ability to produce radiation results that will be available when needed by the field geologist as an aid to geologic mapping and mineral investigations.

To expedite the processing of data, a computer center was established at the College of Petroleum and Minerals, Dhahran. The computer selected is an IBM S/360 Model 50 with 262, 144-byte core storage. An automatic data plotter (EAI Model 430) has also been installed. An integrated computer system that will process large quantities of airborne geophysical data rapidly has been developed.

Eight aeromagnetic profiles were obtained between the African and Arabian shields to determine the magnetic characteristics across the Red Sea rift and provide data relative to the tectonic structure of the rift. The profiles, flown at an altitude of 300 m, covered a belt 42 km wide at approximately the latitude of Jiddah. The data show several magnetic anomalies related to major tectonic features. The principal anomaly, the axial trough anomaly, trends northeast and terminates near the northern edge of the survey area. Depth estimates of approximately 2,000 m show the source of the anomaly to be at or near the bottom of the trough. The three known deep hot brines (Discovery, Chain, and Atlantis II), located within the survey area, appear to be associated with the steep gradients of the axial trough anomaly. If this relationship holds, other hot brine-mineral concentrations may be discovered along the trend of the anomaly. A third lower-amplitude anomaly trending northwest into the Red Sea from the land area south of Jiddah appears to have a much deeper source. This anomaly trends in the same direction as numerous dikes, faults, and magnetic features observed in the Arabian shield rocks.

#### Mineral investigations

G. H. Allcott has investigated pegmatite in granite at the ancient Ablah mine (locality 1, index map) (lat 20°12' N.; long 41°55' E.), which contains an elongated mass of quartz-fluorite rock 20 m wide at the surface. Previous investigators concluded that ancient mining activity was related to the exploitation of fluorite for use as a flux for smelting of ores brought to the area for reduction. A diamond drill hole testing the extension of the outcrop about 125 m below the surface penetrated fluorite sparsely dispersed through-



out the section, locally concentrated to 3 percent  $\text{CaF}_2$ . Small amounts of sulfides were also found, renewing the possibility that ancient mining produced metallic minerals.

In an area of 50 sq km, additional diamond drilling at West Thaniyat (loc. 2) indicates reserves of approximately 200 million metric tons of phosphate rock averaging 23 percent  $\text{P}_2\text{O}_5$  in a bed averaging 1.65 m in thickness. Phosphate is also contained in a second, thinner, stratigraphically higher bed. Lower-grade phosphatic material is found over an extensive area beyond the limits of the higher-grade deposits. Much of the phosphate rock is sandy, but away from the outcrop it becomes more shaly. Beneficiation tests by the Tennessee Valley Authority indicate that the sandy ore can be brought to commercial grade by dry beneficiation; however, the shaly ore does not respond to this treatment. Sixteen quadrangles of the phosphate area covering 1,035 sq mi are being photogrammetrically compiled for publication as topographic maps on orthophotomosaic bases at 1:25,000 scale. A special technique, developed by the U.S. Geological Survey to add color to the black and white orthophotomaps, permits printing of the photographic imagery in tones of various colors as desired. The technique also permits enhancement of the photographic imagery. Geologic overprints are being compiled for six quadrangles covering the West Thaniyat area.

Exploration of the Idsas magnetite deposits (loc. 3) indicates 100 million metric tons or more of presently marginal but readily beneficiable ore containing 19 percent recoverable iron. The host rock for the magnetite is a north-trending belt of the Precambrian Halaban Formation that consists of steeply dipping, intensely folded and fractured propylitized andesite,



diorite, pyroclastic rocks, and minor dolomite and clastic metasediments. These rocks form the upper plate of a major thrust. A zone 3 km long by 400 m wide contains disseminated magnetite in bands, some of which grade into massive tabular bodies several meters wide and a few hundred meters long. Magnetite also fills veinlets and breccia zones. The host rocks are highly uralitized and saussuritized; Conrad Martin, who has been studying the deposits, suggested that the iron deposits originated through uralitization of high-iron pyroxene, rather than from magmatic segregations.

A thin discontinuous cover of nickeliferous laterite overlying about 10 sq km of serpentinite and related rocks in the Jabal Jedair area was explored by shallow pits and trenches by Louis Gonzales. The nickel, as much as 1.5 percent in a few places, was found to be concentrated in the lower part of the laterite and in fractures in underlying rock; cobalt contents are as much as 0.04 percent. Although this deposit is not now of economic importance, it raises the possibility of finding one that is.

At the Ma'dan ancient mine three shallow drill holes explored mineralization along a mafic dike in sericite-chlorite schist. G. H. Allcott reported that zinc, lead, copper, and silver contents as high as 8.75 percent, 2.00 percent, 1.4 percent, and 3.3 ounces per ton, respectively, were found over widths generally less than 1 m. Zoning is suggested by the change of mineralization along the strike. Arsenic and antimony, not common, were found.

A. J. Bodenlos reported that the possibility of finding sulfur deposits along the Red Sea is reasonably good, particularly west of Jabal Dhaylan (loc. 5) and south of Maqna (loc. 6), if it can be assumed that petroleum penetrated the evaporite section. The most favorable area is the Midyan Peninsula because it contains the thickest evaporite section and because it is nearest to known oil fields in the Gulf of Suez and on the west shore of the Red Sea.

## TURKEY

The U.S. Geological Survey project in Turkey, in cooperation with the Maden Tetkik ve Arama Enstitüsü (MTA), is oriented toward exploration for iron and base-metal deposits. Geochemical studies, geologic mapping, and counterpart training form an important part of the program.

### Iron and base-metal investigations

An elongate area (locality 1, index map) in central Turkey was mapped by P. J. Barosh, H. S. Jacobson,



G. W. Leo, and Turkish counterparts of Maden Tetkik ve Arama Enstitüsü (MTA) in conjunction with geochemical, gravity, and magnetic surveys of selected areas. The area includes probable Cretaceous serpentinite; Late Cretaceous conglomerate, mafic volcanics, trachyte-syenite, and limestone; early to middle Tertiary nummulitic limestone, sandstone, conglomerate, and fresh-water limestone; and mafic to intermediate volcanic rocks of late(?) Tertiary age. In the eastern part of the area, Cretaceous mafic volcanic rocks predominate; toward the center serpentinite, limestone, and trachyte-syenite become more abundant; and in the western part limestone constitutes most of the section. All but the youngest rocks are considerably faulted and folded. The predominant structural trend changes from nearly east-west in the east to north-west in the central part. Near the west end of the area is a major north-trending fault zone, west of which the regional structures trend southwest. At the Deveci iron mine in the eastern part of the area, resources are principally siderite that probably originated by metasomatism of limestone intruded by mafic and ultramafic rocks. At the Karakuz mine in the east-central part, metasomatism of trachyte may be related to a syenite intrusion that mobilized iron in adjacent Cretaceous mafic volcanics. A similar origin is ascribed to magnetite enrichment in metasomatized mafic rocks near Hasancelebi. The Otluklisse deposit in the western part of the area apparently represents sinkhole filling in massive limestone by iron-bearing sediments and is not related to any known intrusion. Iron minerals near Kuluncak (central part of loc. 2) appear to be restricted to surficial magnetite-hematite fracture fillings in siliceous rocks formed by weathering of serpentine. Local magnetite anomalies in a few places suggest potentially economic concentrations of magnetite. Lead-zinc deposits in the Kuluncak area are in the form of disseminated pods and narrow galena-sphalerite veins which occur adjacent to trachyte dikes that cut serpentine and also at faulted trachyte-serpentine contacts.

The overall results of this work indicate that central Turkey may have greater potential for economic iron deposits than western Turkey.

The Ergani-Maden area (loc. 2) was mapped by

J. P. Albers, W. R. Griffiths, and three MTA counterparts. The three mines in the district, all operating open-pit massive-sulfide mines, were mapped at 1:500 scale, and a belt 22 km long by 4.5 km wide which includes the three deposits was mapped geologically and sampled geochemically. Within this belt seven target areas ranging from 0.5 to 3.5 km<sup>2</sup> in area have been identified for detailed studies and possible drilling in 1970. Geochemical sampling from four 1:25,000-scale quadrangles also identified a broad northwest-trending copper anomaly that includes the three known deposits and extends in both directions an unknown distance beyond the quadrangles sampled.

The principal rocks in the Maden area are a complexly interlayered sequence of red mudstones and mafic volcanic rocks intruded by a mafic-ultramafic rock complex that is largely but irregularly serpentinized. The red mudstone ranges widely in carbonate content and contains, in addition to irregular bodies of pillow lavas and volcanic breccias, lenses and extremely irregular shaped masses of reef limestone as well as irregular bodies of conglomerate, sandstone, chert, and iron-manganese beds. The limestone is scattered through a thickness of several hundred meters of mudstone and contains abundant fossils of Eocene age.

The rock sequence at Maden strikes generally east-northeast and dips moderately north. It forms the upper plate of a large thrust exposed about 5 km south of Maden which is shown on the geologic map of Turkey to be continuous for about 500 km. Lower-plate rocks are largely of Oligocene age.

Three massive sulfide deposits are known, Ana Yatak, Mihrap Dagi, and Kisabekir. The first two are a replacement of highly chloritized mudstone above serpentinized mafic intrusive rocks. The Kisabekir massive sulfide replaces serpentine just beneath mudstone. In all the deposits chalcopryrite is the copper mineral, and pyrite and pyrrhotite are the associated sulfides.

R. D. Krushensky, mapping four quadrangles in the Edremit area (loc. 3) in western Turkey with Turkish geologists worked out a sequence of regionally metamorphosed sedimentary and volcanic rocks ranging from pre-Triassic to Neogene. The sequence is intruded by several small masses of serpentinized dunite, a granodiorite batholith, and five quartz latite-dacite plugs. Sparse structural evidence indicates a thrust-fault relation between marine Jurassic limestone and sandstone; a second thrust of Permian rocks over Triassic may be present if field identification of Permian fossils is verified.

Base-metal deposits in the mapped area are present in north-northeast-trending, linearly extensive normal fault zones, in irregular areas of silicified arkose, and locally in the contact aureoles of the granodiorite batholith. Deposits in normal fault zones cutting the regionally metamorphosed sedimentary and volcanic rocks, in marine sandstone and shale, and in the marine limestone seem to show the greatest economic potential. These fault zones are mineralized by pyrite and secondary hematite for at least 10 km along strike; galena, sphalerite, and chalcopryrite are present locally in the fault zone, in fractures and bedding planes cut by the fault, and as massive replacements.

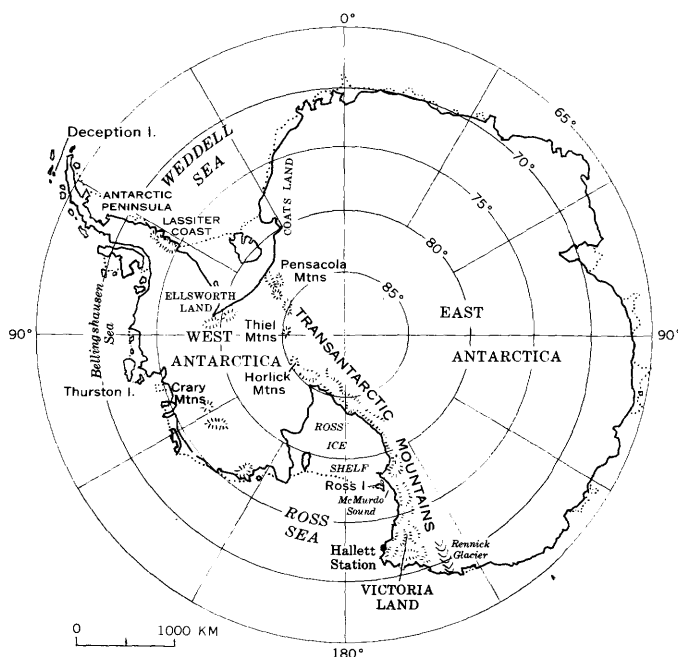
#### **CENTO training program**

The fourth annual Central Treaty Organization (CENTO) training course in geologic mapping and methods of evaluation of mineral deposits was conducted from July 7 to September 6, 1969, under the supervision of E. H. Bailey (USGS) assisted by M. P. Nackowski (University of Utah) and J. W. Barnes (University of Wales, College of Swansea). Intensive training in field methods was given at the Sizma mercury district (loc. 4) in central Turkey to 15 trainees from the CENTO countries—Turkey, Iran, and Pakistan. In this area four mercury deposits in massive limestone are being actively mined. As a large new rotary-furnace plant for extraction of the mercury from the ore had just been put into operation, the mapping and geologic studies of the CENTO group provided much new information of immediate value and also provided the trainees with practice in a variety of mapping techniques.

### **ANTARCTICA**

Geologic field studies and mapping were started during the 1969–70 austral summer in the Lassiter Coast area at the base of the Antarctic Peninsula (see index map) by P. L. Williams and three other Geological Survey geologists. The Lassiter Coast area is the largest unexplored area of exposed mountains in Antarctica. During the same field season paleobotanical studies were made in the central Transantarctic Mountains by J. M. Schopf who accompanied a multidisciplinary project of the Institute of Polar Studies of The Ohio State University.

These field activities, as well as related geologic, geophysical, isotopic, and paleontologic studies in the laboratories of the U.S. Geological Survey, are part of the U.S. Antarctic Research Program sponsored by the Office of Polar Programs of the U.S. National



Science Foundation and logistically supported in Antarctica by the U.S. Navy Operation Deep Freeze. Geodetic fieldwork was initiated in the Lassiter Coast area by a field party of four engineers led by E. G. Schirmacher. This and other fieldwork, aerial photography, and compilation of Antarctic base maps are reported in the section "Mapping in Antarctica" (p. A235-A237).

#### Geology of the Lassiter Coast

The Lassiter Coast, a borderland of the Weddell Sea at the southern end of the Antarctic Peninsula, is a north-northeast-trending mountainous area about 100 by 300 km. The area was unexplored until early November 1969 when four geologists and four topographic engineers established a base camp at 74°27' S., 64°36' W. During the austral summer of 1969-70, the southern one-third of the area, the Latady and Scaife Mountains, was mapped by P. L. Williams, D. L. Schmidt, C. C. Plummer, and L. E. Brown.<sup>112</sup> The area is a terrane of intensely folded sedimentary rocks that were intruded by several small plutons and numerous dikes and sills.

The sedimentary rocks are marine siltstone and shale and minor interbedded arkosic and quartzitic sandstone. Volcanic rocks occur at the top of the suc-

cession, and consist of flows and ash flows of intermediate composition. Fossils of marine mollusks and other invertebrates are locally abundant and indicate a probable Jurassic age. Faunal and floral types and sedimentary structures such as ripple marks and mud cracks suggest deposition in shallow water. These rocks, estimated to aggregate at least several thousand meters in thickness, were tightly to isoclinally folded about gently plunging northeast-southwest axes; locally, folds are overturned and axial planes are generally inclined to the northwest, implying yielding toward the southeast.

Late during the deformational episode, plutons 10-15 km in diameter of granodiorite and adamellite were emplaced. These plutonic rocks probably are a part of the Andean intrusive suite. Contact metamorphic effects adjacent to the plutons extend several hundred meters into the sedimentary country rock, and petrographic studies by C. C. Plummer show conclusively that in places penetrative deformation accompanied thermal metamorphism. Adjacent to the plutons, the northeast structural grain in the sedimentary rocks is commonly deflected, and fold plunges locally are steep.

Dikes and sills, occurring throughout the mapped area, range in composition from rhyolite to basalt and in relative age from preplutonic to postplutonic.

#### Permian and Triassic paleobotany

Important new collections of Permian and Triassic plant material were made in the Beardmore Glacier area of the central Transantarctic Mountains by J. M. Schopf. Two deposits of petrified plant remains representing peat of Permian age and Triassic age were found on Mount Augusta and Fremouw Peak, respectively, in a state of permineralized preservation. Material elsewhere was transformed to coal by pressure, heat, and geologic time. Plant roots, leaves, fertile structures, pollen grains, and wood-decaying fungi in these deposits are mostly free of distortion. Both deposits will provide much-needed information about ancient plant anatomy to permit precise comparison. They also provide excellent examples of the plant remains that contributed to peat (and hence to coal) deposits in Gondwanaland. The apparent differences of Gondwana coals, owing to the presence of plants very different from those in northern floras, have not previously been clearly shown. Aside from variously preserved specimens of fossil wood, similar material has not been reported from any other of the Gondwana continents.

<sup>112</sup> Williams, P. L., Schmidt, D. L., Plummer, C. C., and Brown, L. E., 1970, Geology of the Lassiter Coast area, Antarctic Peninsula—a preliminary report: Presented at the Symposium on Antarctic Geology, Oslo, Norway, August 1970.

### **The Weddell orogeny, a major early Mesozoic deformation**

The Weddell orogeny of probable early Mesozoic age was named and defined by A. B. Ford<sup>113</sup> in the Pensacola Mountains. The sedimentary rocks, more than 9,000 m thick, in the Pensacola Mountains provide an exceptionally complete record from late Precambrian through Paleozoic time. A history of multiple deformation is clearly recorded by well-exposed folded angular unconformities that separate the sedimentary suite into three sequences. A lower limit of Permian for the folding of the third and youngest sequence is provided by a *Glossopteris* flora in the highest sandstone unit. An upper limit of early Jurassic age is provided by K-Ar ages of rocks and separated mineral phases from the postorogenic stratiform Dufek intrusion. The Weddell orogeny is probably of Triassic age and hence is not correlative with the early Tertiary "Andean" deformation in the Antarctic Peninsula and Ellsworth Land. Other scattered and inconclusive evidence suggests that the Weddell orogeny may have been widespread in the southern Weddell Sea region but that its effects have either not been found or not recognized in the western Weddell Sea area.

### **Upper Paleozoic nonmarine tillite in the Pensacola Mountains**

Late Paleozoic tillite deposits more than 600 m thick studied by D. L. Schmidt in the Pensacola Mountains

contain calcite that was isotopically analyzed by Irving Friedman. The calcite is a minor constituent of the tillite and occurs as primary depositional calcite and as diagenetic calcite. The C<sup>13</sup> and O<sup>18</sup> isotopic abundances conclusively indicate that the tillite was laid down by waters of continental origin. In addition, deposition was probably at low altitude because the isotopic composition of the water, which must have been in equilibrium with the carbonates, is similar to that found near sea level in present-day Antarctica, and differs from carbonate laid down in water from the present-day Polar Plateau above 3,000 m. A series of 26 calcite samples representing several of the major Paleozoic sedimentary rock units of the Pensacola Mountains as well as the tillite were analyzed; distinctly marine deposits gave carbon and oxygen isotopic abundances characteristic of marine deposition.

### **A "climatic" reconstruction of Gondwanaland**

The anomalous distribution of Southern Hemisphere and Indian floras has long been recognized. Recent studies of sea-floor spreading have aided in explaining the now widely separated but similar Permian floras within this area. These and later plant fossils, together with submarine topography, now suggest a historical sequence of continental disruption for Gondwanaland which was centered in the present area of the Indian Ocean. A reconstruction of Gondwanaland by J. M. Schopf (r2246) is based on (1) the Permian climatic zonation of the *Glossopteris* flora, (2) distribution of the epicontinental seas, (3) location of the postglacial lake or sea(?) within the landmass, and (4) distribution of latest Permian or Triassic folding.

<sup>113</sup> Ford, A. B., 1970. The Weddell orogeny—early Mesozoic deformation at the Weddell Sea margin: Presented at the Symposium on Antarctic Geology, Oslo, Norway, August 1970.



## TOPOGRAPHIC SURVEYS AND MAPPING

### PROGRAM MANAGEMENT

#### Federal mapping coordination

The responsibility for governmentwide coordination of federally funded domestic surveying and mapping activities was assigned to the Department of the Interior (and subsequently delegated to the U.S. Geological Survey) by the U.S. Bureau of the 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 mapping data and existing aerial photographs.

Initial steps have been taken to identify those agencies and programs through which Federal funds have been and are expended for mapping, aerial photography, and related survey data. It is planned to establish liaison with all of the pertinent agencies and to determine the volume, quality, and nature of mapping materials available from each agency. By consultation, the appropriate mechanisms and interagency agreements will be developed to expedite the transfer of available map-related information to the Map Information Office.

Letters were sent to the Secretaries of Departments, heads of independent agencies, Federal cochairmen of all regional commissions, and chiefs of the United States sections of the Canadian and Mexican National Boundary Commissions. These letters explained the coordination responsibility assigned to the Geological Survey and requested the appointment of a departmental or agency representative with whom the Coordinator of Federal Mapping might confer. In response, 49 departmental and agency representatives to the mapping coordination effort have been named.

The Coordinator met with representatives of 38 agencies to discuss facets of coordination. Meetings are planned with representatives of the remaining agencies that have designated liaison officials.

#### Automation in program management

The design of an automated program data bank system to coordinate component files with one another by computer has advanced during the past year.

A system was programed and installed for entering aerial photography data elements into the program data bank and for producing several management reports.

The new automated accounting and production reporting system, Topographic Resources and Cost Evaluation (TRACE), became operational. Work continued on integrating this system with the program data bank; operating program system; and the accounting, personnel, and payroll systems.

Adjustments were incorporated in the Resources Balancing System to bring several features and reports into conformity with TRACE. Features are being added to develop short-range operating programs or production schedules which will be totally in consonance with the longer range operating programs.

### MAPPING ACCOMPLISHMENTS

#### Objectives of the National Topographic Program

The major topographic function of the U.S. Geological Survey is to prepare and maintain maps of the National Topographic Series, covering the United States proper and other areas under its sovereignty. The individual series, at various scales, constitute a fundamental part of the basic data needed to inventory, develop, and manage the natural resources of the country. Other topographic functions of the Geological Survey include the production of special maps, and research and development in techniques and instrumentation.

Procedures for obtaining copies of the map products of the Survey are given under "How to Order Publications" in the section "Publications Program" (p. A247-A249).

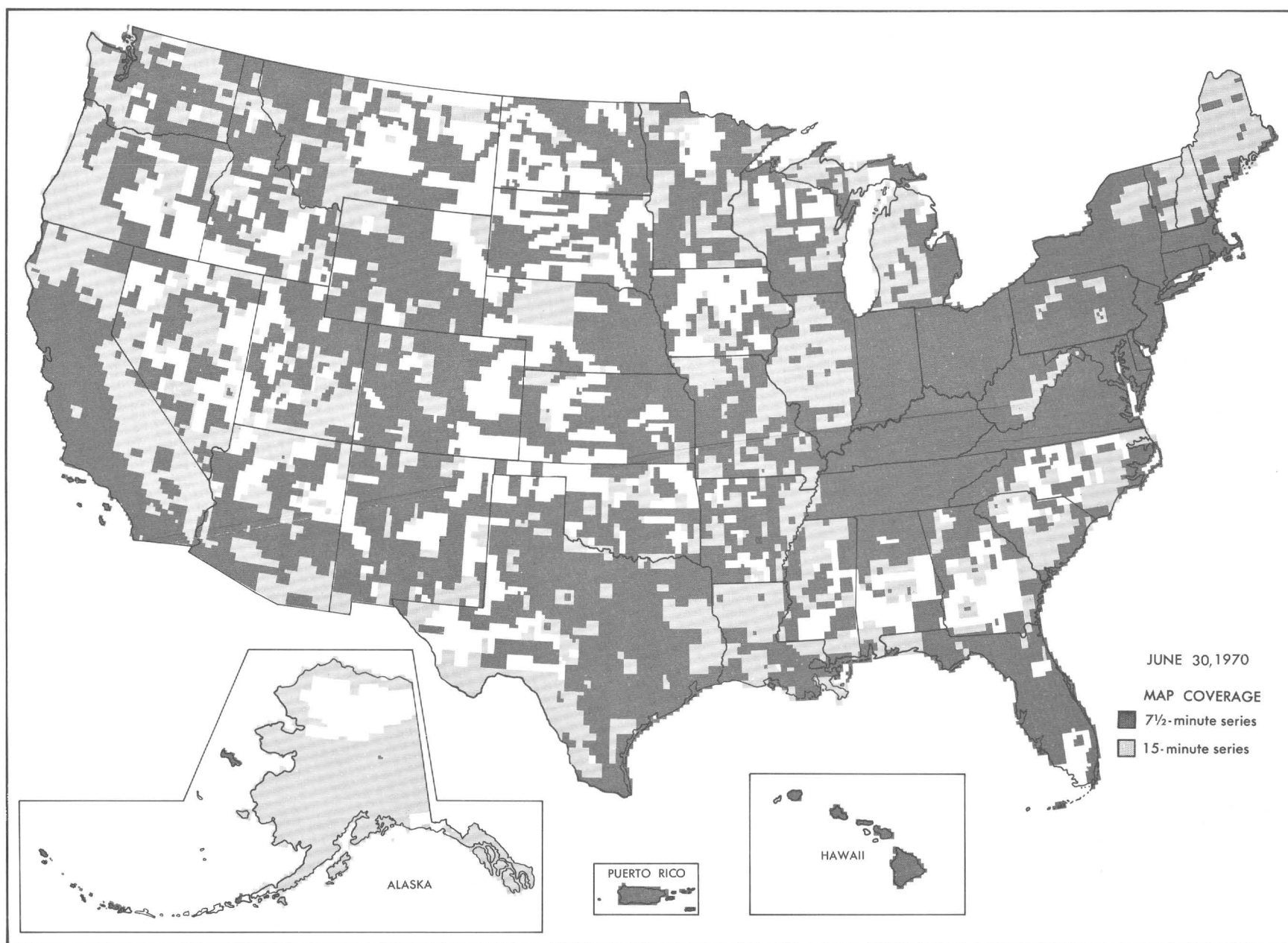


FIGURE 5.—Status of 7½- and 15-minute quadrangle mapping.



### 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 82 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 in advance form.

During fiscal year 1970, 1,179 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, 430 new maps at a scale of 1:24,000, equivalent to about 0.7 percent of the total area, were published to replace 15-minute quadrangle maps (1:62,500 scale) which did not meet present needs. Figure 5 shows the extent and location of the current topographic map coverage.

### Map revision and maintenance

Map revision is necessary to show changes in the terrain and additions of manmade features, such as roads, buildings, and reservoirs. During fiscal year 1970, 693 general-purpose quadrangle maps of the 7½-minute series and 17 quadrangles of the 15-minute series were revised and forwarded for printing. Most of these maps are in urban areas or in States that are completely mapped in the 7½-minute series. About 1,500 maps are currently in the revision program (fig. 6).

Revision methods vary, but usually are a combination of photogrammetric, field, and cartographic procedures designed to update map content and to maintain or improve the original accuracy of the map. The interim revision method was introduced in fiscal year 1967. Information about changes in cultural and planimetric features that have occurred in an area is obtained from aerial photographs, and the new data are printed in purple over the previously shown map data. This type of revision relies primarily on photo-interpretation and involves no fieldwork.

Interim revision was applied first in the urban and suburban areas of the country, where rapid expansion and development caused many maps to become out of date. As the revision backlog in urban areas is reduced, the interim revision program is being applied to rural areas.

In fiscal year 1970, 749 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 part of the 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 7 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 43 maps covering 47 States and the District of Columbia (fig. 8). All these maps are published in planimetric editions; contour and shaded-relief editions are also available for most of them. Eight of the maps, Arizona, California, Colorado, Illinois, Missouri, New Jersey, Ohio, and Virginia, are being revised. Other States are covered by an earlier series, also shown in figure 8.

### National-park maps

Maps of 42 of the 214 national parks, monuments, historic sites, and other areas administered by the National Park Service have been published. 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	Cedar Breaks National Monument, Utah
Badlands National Monument, S. Dak.	Colonial National Monument (Yorktown Battlefield), Va.
Bandelier National Monument, N. Mex.	Colorado National Monument, Colo.
Black Canyon of the Gunnison National Monument, Colo.	Crater Lake National Park, Oreg.
Bryce Canyon National Park, Utah	Craters of the Moon National Monument, Idaho
Canyon de Chelly National Monument, Ariz.	Custer Battlefield, Mont.
Canyonlands National Park, Utah	Devils Tower National Monument, Wyo.
Carlsbad Caverns National Park, N. Mex.	Dinosaur National Monument, Colo.-Utah
	Franklin D. Roosevelt National Historic Site, N.Y.



FIGURE 6.—Revision in progress, 7½- and 15-minute series topographic maps.

Glacier National Park, Mont.	Olympic National Park, Wash.
Grand Canyon National Monument, Ariz.	Petrified Forest National Park, Ariz.
Grand Canyon National Park, Ariz.	Rocky Mountain National Park, Colo.
Grand Teton National Park, Wyo.	Scotts Bluff National Monument, Nebr.
Great Sand Dunes National Monument, Colo.	Sequoia and Kings Canyon National Parks, Calif.
Great Smoky Mountains National Park, N.C.-Tenn. (2 sheets)	Shenandoah National Park, Va. (2 sheets)
Great Smoky Mountains National Park and vicinity, N.C.-Tenn.	Vanderbilt Mansion National Historic Site, N.Y.
Isle Royale National Park, Mich.	Vicksburg National Military Park, Miss.
Lassen Volcanic National Park, Calif.	Wind Cave National Park, S. Dak.
Mammoth Cave National Park, Ky.	Yellowstone National Park, Wyo.-Mont.-Idaho
Mesa Verde National Park, Colo.	Yosemite National Park, Calif.
Mount McKinley National Park, Alaska	Yosemite Valley, Calif.
Mount Rainier National Park, Wash.	Zion National Park (Kolob section), Utah
	Zion National Park (Zion Canyon section), Utah

Maps of the Grand Teton National Park 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 part of the 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 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. 9).

Two of the maps, Hudson River and San Francisco Bay, are no longer available as IMW maps, but the

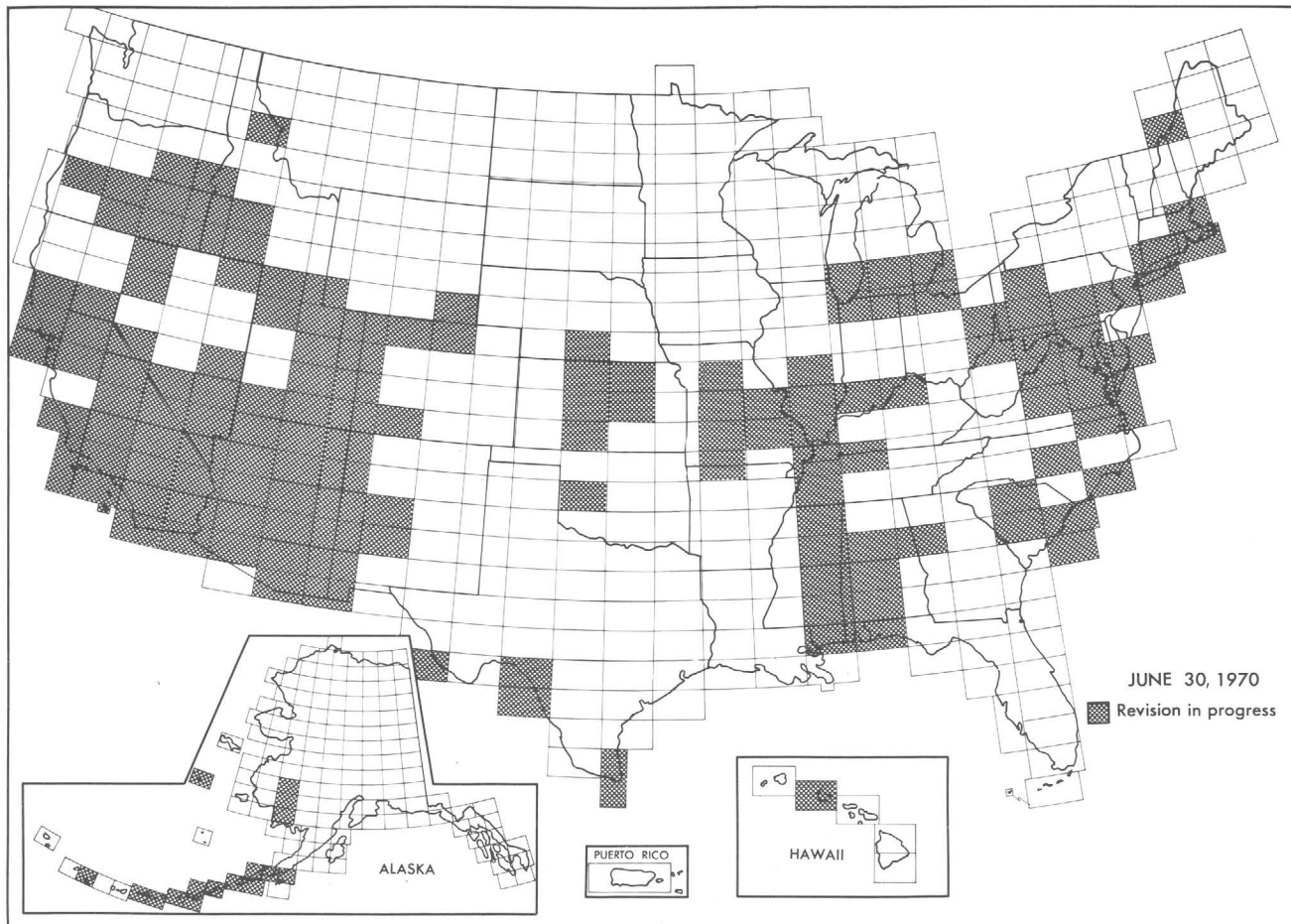


FIGURE 7.—Revision of 1:250,000-scale topographic maps.

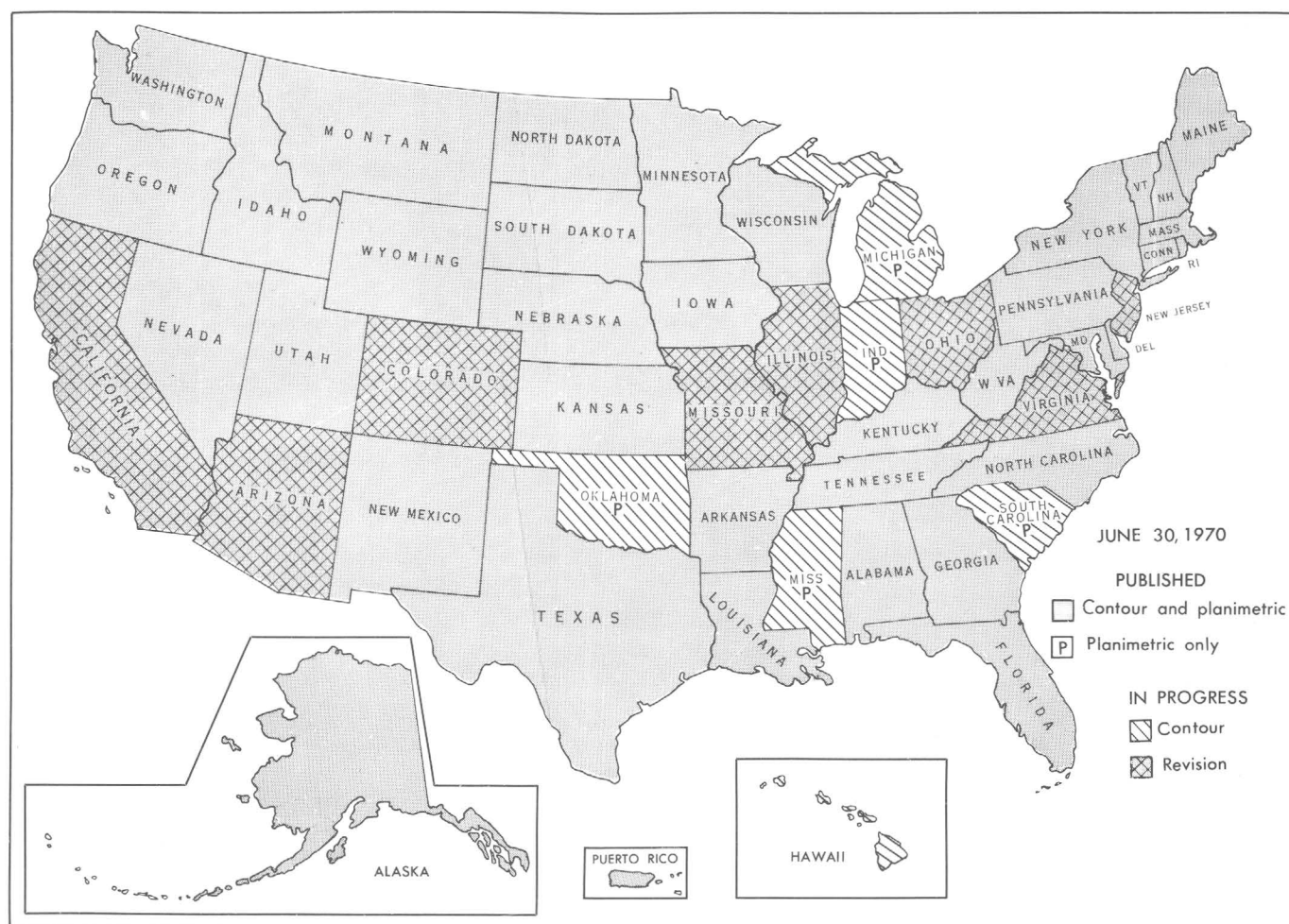


FIGURE 8.—Status of State maps.

areas are covered by maps in the military series. Maps of both the IMW and the military series are available for Boston, Chesapeake Bay, Hatteras, Mississippi Delta, Mount Shasta, and Point Conception. In addition, the American Geographical Society published the Sonora, Chihuahua, and Monterrey maps; and Canada published the Regina and Ottawa maps. Puerto Rico is covered by two maps compiled by the American Geographical Society and published by both the Society and TOPOCOM.

Work in progress includes five new maps: Blue Ridge, Quebec, Lookout Mountain, Des Moines, and Ozark Mountains.

#### Aerial photography

In support of topographic mapping activities in fiscal year 1970, the U.S. Geological Survey contracted for vertical aerial photography of approximately 247,000 sq mi in the United States. Cameras with focal lengths of 6 inches were used for 220,000 sq mi of the photographic coverage, which included 58,000 sq mi taken at about 40,000 feet above ground with a jet

aircraft. The largest single photographic project covered a 28,000-sq-mi area of the north slope of the Brooks Range in Alaska. Minor projects were photographed with cameras of 3½-, 8¼-, and 12-inch focal length.

#### Orthophotomapping

Following extensive experimentation to determine types of suitable terrain and to develop cartographic techniques, orthophotomaps of selected areas are being published as standard editions instead of conventional line maps. Areas of low relief, sparse culture, swamps, desert, and coastal plains are often portrayed more adequately by orthophotomaps than by conventional cartographic symbolization. The technique is particularly effective for mapping large swamp areas, such as the Okefenokee Swamp in Georgia and the Big Cypress Swamp and the Everglades of Florida.

Eleven orthophotomaps were published as experimental editions, and nine are in progress. Seventeen have been published as standard editions, and 158 are in the program for 1:24,000-scale publication.



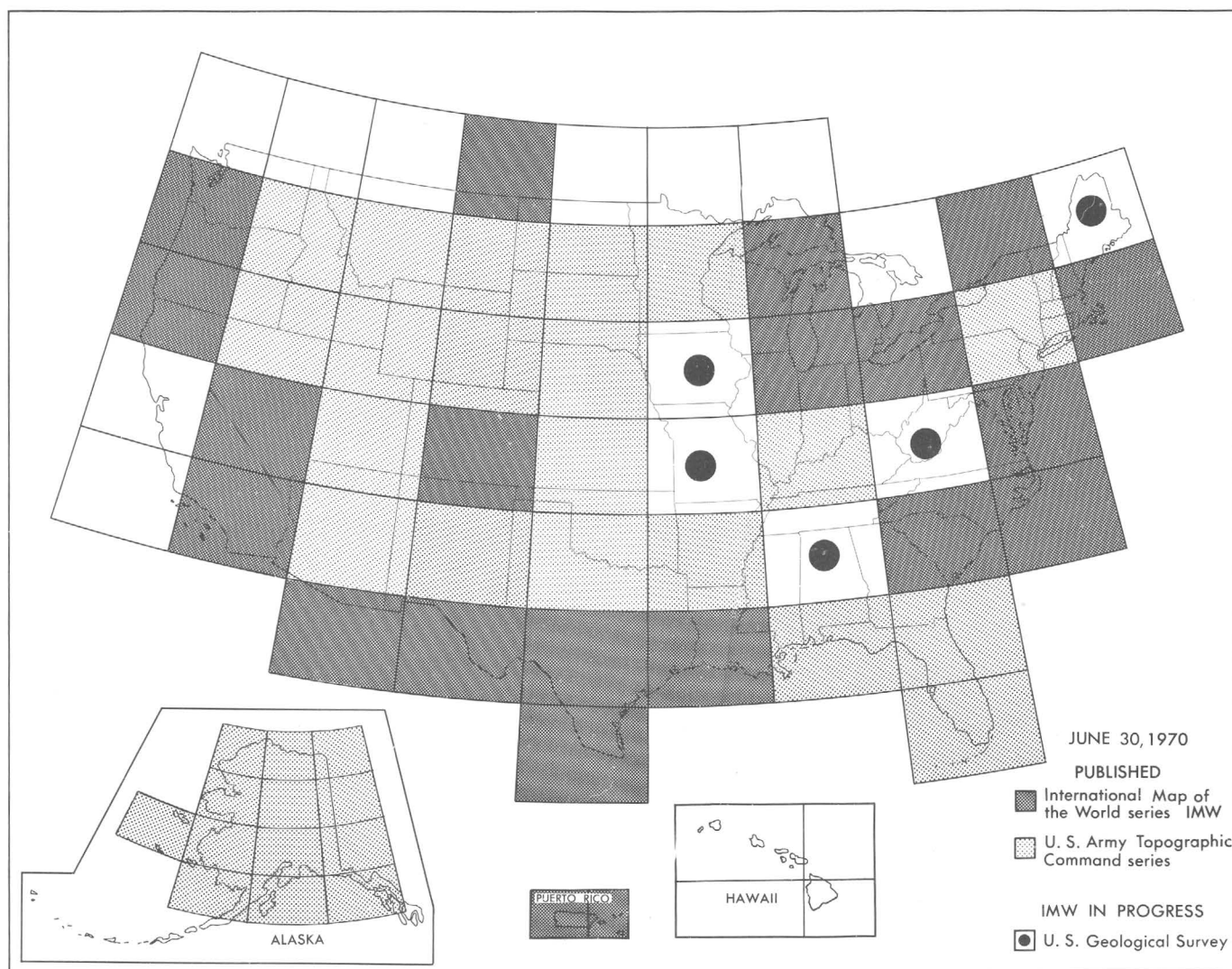


FIGURE 9.—Status of 1:1,000,000-scale topographic maps.

### Arctic Alaska mapping

Topographic mapping was started for approximately 26,700 sq mi of the central Brooks Range and North Slope area that is currently mapped at 1:250,000 scale. The new maps will be published at 1:63,360 scale with contour intervals of 50 and 100 feet. The area encompasses much of the transportation corridor to the North Slope exploration area and includes the proposed trans-Alaska pipeline route north of the Yukon River.

Twelve orthophotomaps at 1:24,000 scale will also be prepared for approximately 550 sq mi in the Prudhoe Bay area, where current oil exploration is concentrated.

## MAPPING IN ANTARCTICA

The U.S. Geological Survey continued to assist the National Science Foundation in its U.S. Antarctic Research Program (USARP) by furnishing six field

engineers and a cartographer for the austral season of 1969–70. The field engineers established geodetic control for the topographic mapping program, made astronomical observations at Byrd and South Pole Stations, and conducted scientific and engineering surveys in support of other disciplines and activities. The cartographer was assigned to photographic liaison duty with the U.S. Navy.

### Topographic field operations

E. G. Schirmacher, J. R. Heiser, J. L. Harry, and F. J. Geier established control for the Lassiter Coast topographic mapping project. An astronomical station was established at Wetmore Glacier base camp by stellar observations, and a traverse was run 140 miles southward into the Wilkins Mountains, establishing control for approximately 6,500 sq. mi. The glaciological ice-movement survey stakes across the Wetmore Glacier were observed, and the U.S. Naval Civil Engi-

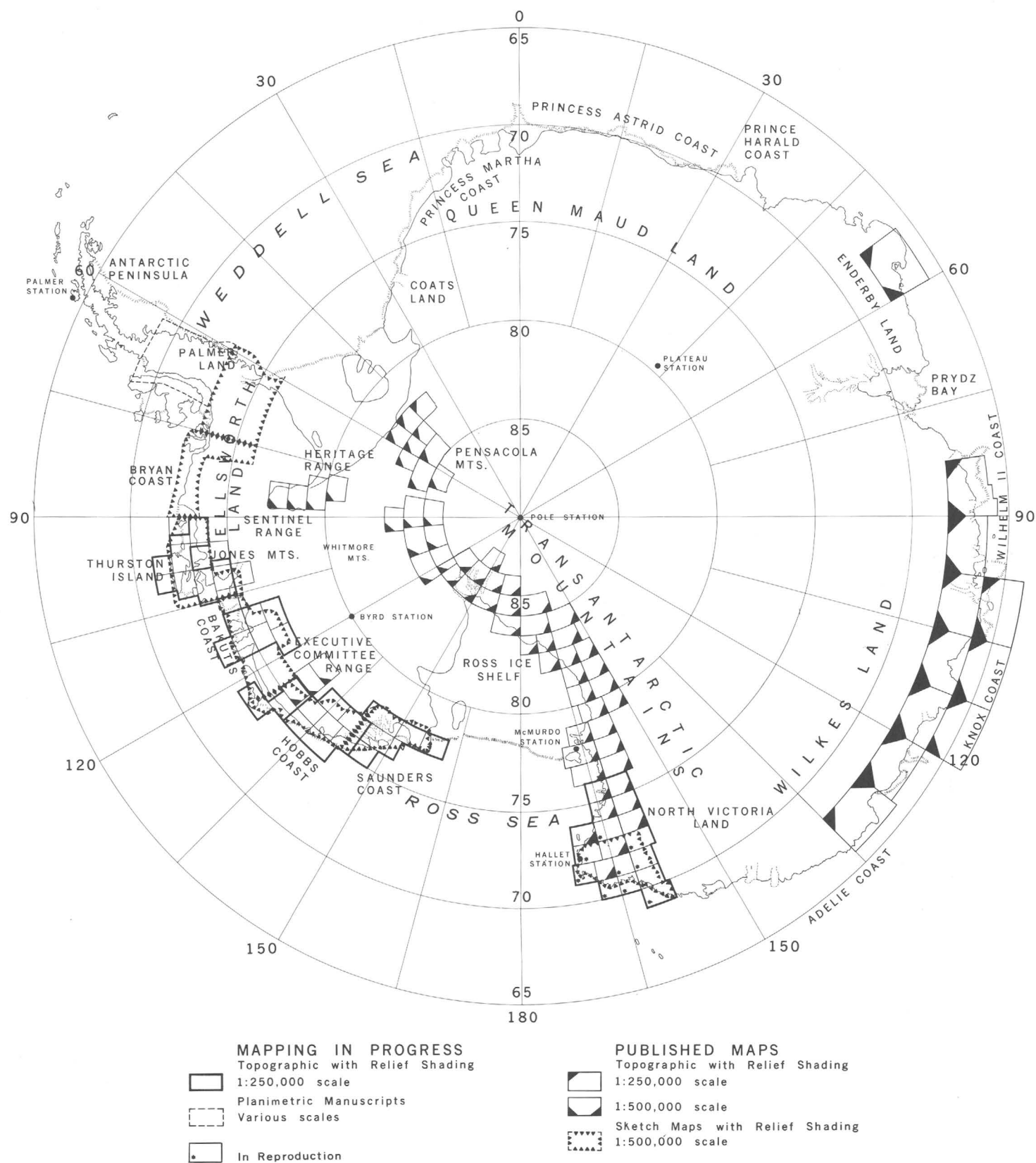


FIGURE 10.—Index map of Antarctica, showing status of topographic mapping by the U.S. Geological Survey as of June 30, 1970.

neering Laboratory ice-strain net on the Ross Ice Shelf between Hut Point and the Koettlitz Glacier were reobserved.

T. E. Spring and L. L. Amos made astronomic observations for the National Science Foundation and provided other surveying services for USARP, including (1) reobserving for geographic position at both the South Pole and Byrd Station astronomical stations, (2) setting a wooden post at the geographic South Pole, (3) establishing elevations on the automatic satellite scientific tower at Byrd Station, (4) measuring geodetic azimuths for the U.S. Coast and Geodetic Survey geomagnetic projects at both Byrd and South Pole Stations, and (5) making observations for a solar azimuth at three stations along the Byrd Station ice-strain net for The Ohio State University.

#### **Aerial photography**

Cartographic aerial photography was deleted from this year's program, but F. S. Brownworth, program coordinator and technical adviser on aerial photography, supervised the photography of approximately 7,000 sq mi over Edward VII Peninsula, portions of Coats Land, the Shackleton Range, and Theron Mountains. In addition, almost the entire noncartographic aerial photography requirement for the USARP scientific community was completed.

#### **Cartographic activities**

The status of U.S. Geological Survey topographic mapping in Antarctica is shown in figure 10. Fourteen 1:250,000-scale reconnaissance topographic maps were completed in fiscal year 1970. Four of these maps, covering 19,300 sq mi, have been published and 10, covering 39,000 sq mi, should be published in the second quarter of 1971. Production is underway on 19 maps at 1:250,000 scale, covering approximately 103,000 sq mi, and on one sketch map at 1:500,000 scale, covering approximately 56,200 sq mi.

### **TRUST TERRITORY MAPPING**

Map compilation was completed for Tinian, Aguijan, Rota, and Saipan in the Marianas District, as part of the topographic mapping program provided for in 1968 by an agreement between the Trust Territory of the Pacific Islands and the U.S. Geological Survey. Four field engineers are assigned to field-survey operations in the other districts.

Maps will be published at 1:25,000 scale, with basic contour intervals of 5 and 10 m, and will be printed at maximum press size instead of standard 7½-minute format to permit whole islands to be shown on one

sheet, thus requiring as few sheets as possible for the project.

In addition to the topographic mapping program, 15 field engineers are assigned to the Trust Territory Land Cadaster program, under the technical direction of the Trust Territory Division of Lands and Surveys.

### **NATIONAL ATLAS**

The National Atlas of the United States of America is now in the final phases of completion. This 450-page volume will be 19×14 inches in size with about 30 percent of the maps opening to double-page spreads of 19×28 inches.

As of July 1, 1970, all National Atlas maps have been printed for the bound edition or are awaiting printing. In addition, 46 pages have been published as individual map sheets for sale to the public.

During the past year, additional dummies of the atlas were made up and tested, and, as a result, final binding specifications have been prepared. It is expected that a contract for binding will be awarded shortly after July 1, 1970, with delivery of the first volumes in December 1970. A contract for printing 6 Mylar pages (19×14 inches), to be inserted into the back of each bound volume, will be awarded shortly after July 1, 1970, with delivery in 45 days.

All names (41,000) that will appear in the atlas index have been processed. Approximately half the names have been alphabetized and prepared for publication. The completed index, which will be in the back of the atlas, will have all entries coded to the atlas map showing individual features at the largest scale.

### **INTERNATIONAL ASSISTANCE PROGRAMS**

#### **Saudi Arabia**

The U.S. Geological Survey is continuing to assist the Ministry of Petroleum and Mineral Resources of Saudi Arabia in assessing the mineral potential of the Precambrian shield area of central and western Saudi Arabia.

Since September 1969 the Geological Survey has provided a photogrammetric specialist and an engineer geodetic specialist to support these investigations. Late in 1969, another photogrammetric specialist was sent to Riyadh for temporary duty with the Aerial Survey Department.

Twenty quadrangle maps at 1:25,000 scale have been completed through photogrammetric compilation at the Aerial Survey Department. Sixteen quadrangle



orthophotomaps have been completed through cartographic phases in the United States. Four of these maps were printed by the Geological Survey, and 12 were printed in Lebanon for the Kingdom of Saudi Arabia.

### **Brazil**

The U.S. Geological Survey is participating in the Technical Assistance Loan Agreement, administered by the U.S. Agency for International Development (AID), by training personnel of the Departamento Nacional de Aguas e Energia Eletrica of Brazil.

Since September 1969 three participants from the Serviço de Fotogrametria were trained for 1 month in obtaining and using aerial photographs for mapping, and three were trained for 6 months in photogrammetry, management, and programing. A participant from the Directoria do Serviço Geografico completed training in photogrammetry and management, and another began a 1-year training program in topographic mapping operations in January 1970.

A Geological Survey photogrammetric specialist visited Brazil to assist the Serviço de Fotogrametria and the Directoria do Serviço Geografico in developing computer programs for analytical and semi-analytical photogrammetry.

### **Liberia**

The geological exploration and resources appraisal project in Liberia is a cooperative effort of the Government of Liberia and the U.S. Agency for International Development (AID). The U.S. Geological Survey had one cartographer in Liberia during fiscal year 1970 to support this program. The Geological Survey is compiling 1:40,000-scale form-line maps of all of Liberia. To date, 346 form-line maps have been completed, 104 during fiscal year 1970. The form-line mapping will be completed during fiscal year 1971. From these maps, small-scale maps will be made and used for publishing geologic data. The primary source data for the form-line maps are recent U.S. Air Force photographs and older photographs and maps.

### **Training programs and inquiries**

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, participants came from Afghanistan, Argentina, Brazil, Guyana, India, and Indonesia. They were sponsored by the United Nations, U.S. Agency for International Development, foreign governments, other international organizations, and special fellowship funds. Many

requests for technical reports, for information on sources of equipment, and for resolution of mapping problems are received from foreign countries.

## **RESEARCH AND DEVELOPMENT**

### **FIELD SURVEYS**

#### **Surveying tower**

A new truck-mounted tower, which can be extended from 32 to 60 feet and plumbed over a station mark in 2.5 hours, has been designed. The tower consists of two inner sections, two outer sections, and a detachable platform and instrument stand. Parts for a 15-foot extension are also included with each tower so that the effective height can be increased to 75 feet.

The four sections, nested and mounted on the truck hoist for transport are 32 feet long; they can be extended to a working height of 60 feet. The telescoping sections are extended and retracted on permanently lubricated hard-rubber rollers. For safety during extension, a roller-and-sling system holds the upper section of the outer tower while the connector plates are bolted in place.

The instrument stand, a 6-inch aluminum tube 56 feet long, extends the full length of the tower and is mounted directly to the top of the stabilization tank; it is held vertical by three sets of horizontal supports attached to the inner tower. A device to aid in centering the tower over a station has been provided.

#### **Metal-rod bench-mark supports**

Since 1964 copper-coated steel rods have been developed and used to support bench-mark tablets. The 5-foot rod sections are driven with a gasoline-powered impact hammer. The sections are joined with brass sleeves, which are crimped with a hydraulic compressing tool. After the rod assembly is driven to refusal, the bench-mark tablet is crimped to the top of the last rod section.

Experience with driven rods during the past few years has shown that unthreaded sleeves crimped to unthreaded rods sometimes separate. Experimentation has shown that joints made with solder hold very well and that crimped threaded couplings are also satisfactory. Rod sections are threaded by a cold-rolling process that leaves the copper coating intact. Threaded brass tubing is used for couplings which are tightened with a wrench and crimped. The crimping deforms the threads to produce a permanent bond.

A number of other metals have been tested as bench-mark supports, including steel, wrought iron, stainless steel, stainless-steel-clad steel, galvanized steel, alumi-

num pipe, and aluminum rods. All these metals had serious drawbacks, except perhaps wrought iron, which is still under investigation.

#### **Geodetic computations programs**

The master geodetic computations program designed to handle all computations in a survey network was used during the year for processing most control survey data. However, the original plan for a single program to serve all purposes has been modified as a result of practical experience. Each region office maintains a version of the program adapted to particular requirements.

Two programs were written during the year that are not part of the master control program. VERTA performs a least-squares adjustment of leveling nets. The program adjusts nets containing a maximum of 225 junction points, accepts data punched directly from fieldnotes, and prints out accuracy statistics as well as adjusted elevations. The program is on disk file and may be called into operation by any computer terminal. MAPAC computes a horizontal accuracy test for as many as four quadrangles, analyzes the results, and prints a report. Input data are field positions of test points and coordinatograph readings of map points. The map may be in any position on the coordinatograph. The program makes a least-squares fit of the map graticule before computing and listing the map errors.

The power of modern computers can be used in planning survey networks so as to obtain the required results at a minimum cost. One approach is to use the method of error propagation in a planned network, based on assumed measurements, then modify the plan until the most economical design is developed. A second approach is to express the total cost as a function of the main variables, then find the minimum of the function. In either case the mathematical problems are considerable, and only the availability of large computers make such analyses feasible. A start has been made with the development of two experimental programs—STATION ADJUSTMENT and POSITION ADJUSTMENT BY VARIATION OF COORDINATES. With these two programs, it is possible to propagate errors through any type of survey, starting with field instrument data. However, substantial development and improvement are needed before computer processing can be used practically to design optimal survey networks.

#### **Analysis of Byrd Station strain net**

In cooperation with glaciologists from Ohio State University, a strain net was set up near Byrd Station, Antarctica, in the 1963–64 season to study the dynamics

of a flowing ice sheet. The net extends from Byrd Station 166 km upslope (northeast) to a major divide in the ice and consists of 52 quadrilaterals with 3-km sides. Stations are marked with 4×4-inch posts frozen in the ice.

The net was surveyed first in the 1963–64 season and was resurveyed in the 1967–68 season. In 1969, strain rates for each quadrilateral in the net were computed by (1) making a least-squares adjustment of each survey; (2) determining distance and azimuth changes for each line in the net; (3) dividing these changes by the elapsed time between surveys to determine linear and shear strain rates; and (4) adjusting the strain rates to fit a homogeneous strain model.

### **PHOTOGRAMMETRY**

#### **Aerotriangulation**

Accuracy tests of map manuscripts were analyzed on a statistical basis to evaluate the effect of the changeover during the last 4 years from aerotriangulation by stereotemplates to semianalytical aerotriangulation for establishing horizontal mapping control. The analysis included data from 48 tests of maps controlled by stereotemplates and 25 tests of maps controlled by semianalytical methods. A definite trend toward higher accuracy from semianalytical methods was shown by the results. The average root-mean-square error was 19.3 feet for the templet-based maps compared with 15.2 feet for the maps controlled by semianalytical methods. Refinement of semianalytical methods was continued, and further improvement in map accuracy is expected.

#### **Equipment developments**

A program is underway to convert all direct-viewing stereoplotters (Kelsh and ER-55) to use quartz-halogen lamps. Although quartz-halogen light bulbs have been on the market for several years, manufacturers have only recently adapted them for applications other than photographic floodlights. These new lamps have many features which make them superior to conventional incandescent lamps. They are small, extremely bright, and they retain full efficiency throughout their life. Bulb envelopes are made of fused quartz, which has a high softening temperature, low coefficient of expansion, and optical clarity. The halogen inside the lamp, through a regenerative cycle, practically eliminates lamp blackening—a condition which destroys the usefulness of ordinary bulbs in stereoplotters.

The most recent StereoImage Alternator development is a shutter designed to operate inside the lamp-house of an ER-55 projector. This new shutter covers

the entire projected image, whereas the old shutter covered only a narrow strip of the image in the viewing area of the stereomodel. The existing projector lamphouse was utilized in the design.

#### **Base-sheet plotting**

A new computer program was written which generates instructions on tape for an automatic coordinate plotter to produce 1:250,000-scale map base sheets including Universal Transverse Mercator (UTM) grid ticks, map border, control points, and labels. Input includes a format card for reading in data of points to be plotted, a title card for labeling printed output, the plotting constants for the particular plotter being used, and other constants, such as dimensions for the sheet being plotted. The computer program is similar to the one now used to plot 7½-minute 1:24,000-scale map base sheets but is more convenient to use because it automatically computes much of the needed data, such as UTM grid coordinates, projection-line intersection spacings, and the plane coordinate values of the projection-line intersections.

#### **Automatic orthophotosystem**

A new system to automate the production of orthophotographs is under development. The basic components of the system are a profiling device, the Autoline, and the Orthophotomat. Profiles derived by a profiler will be used as input to the Autoline—an automatic line follower which will operate the Orthophotomat.

Both manual and automatic profiling techniques are being developed. For manual scanning of terrain profiles, an analog profiler was designed and is being built. It incorporates a direct-projection stereoscopic plotter and a standard tracing-table platen mounted on the carriage and arms of a coordinatograph. Manual control for stepover in  $x$  and  $z$  motion are provided. A profile scanned by the operator in the  $y$  and  $z$  plane is recorded by means of mechanical linkage on a paper or plastic sheet placed in the  $x$  and  $y$  plane. The recorded profile is either scribed or inked. The automatic technique uses optical principles and a photographic process to record profiles from a stereoscopic model. The model is formed with edge-enhanced photographs, one positive and the other negative. Corresponding ray intersections from the positive and negative images form a continuous gray line which can be recorded on film. Continuing research is aimed at refining the technique so that profiles of an entire model can be recorded in one exposure.

The Autoline follows profiles automatically by

means of two cadmium sulfide photocells, mounted in juxtaposition to straddle the profile. The electronic circuitry operates through servomotors to keep the light entering the photocells balanced, so that the scanning head is centered on the profile with a precision of 2  $\mu$ m. The photocell sensor travels in the  $y$  direction at a constant speed, and its deviation from the  $y$  axis of the profile indicates the  $z$  component of the profile. As the Autoline follows the profiles, synchronized and coordinate signals are transmitted to the Orthophotomat to control the  $y$  and  $z$  scanning motions and the stepover in  $x$  to the next profile.

The Orthophotomat, a single-projector instrument for off-line automatic production of orthophotographs, was designed, and the prototype is being built. This instrument is the final element of the orthophotosystem. It uses a modified Kelsh projector with  $\times 2.8$  magnification and is provided with  $x$ -tilt,  $y$ -tilt, and swing motions. The 27 $\times$ 27-inch film platen will move 150 mm in the  $z$  direction and has a vacuum system for holding the film flat. The  $x$  and  $y$  drives can be disconnected and the  $z$  motion operated manually for orientation of the image to the controlling profile. The  $x$  stepover has a least-count movement of 0.001 inch. Scanning slots of different widths can be installed for use in different types of terrain.

#### **Image correlating and measuring system**

The second-generation production version of the image correlator built for the U.S. Geological Survey by the BAI Corp. is being tested for operational use in aerotriangulation. Other potential uses of the correlator are in camera calibration, multispectral imagery registration, correlation of metric and nonmetric imagery, and registration of time-variant imagery. The main components of the system are the image correlator, with punched-card memory, and a comparator with associated readout and recording equipment. Auxiliary components include the point finder, for approximate pointing, and TV monitor, for fine optical pointing.

The operator, instead of manually pointing and marking a photogrammetric pass point, uses the correlator to scan an annular area of imagery around the point. A video signal, or signature, is developed which uniquely defines the scanned scene. The operator can record the signature in binary form on a punched card. Subsequently, he can reestablish the reference signature from the punched card and use it to correlate the same scene from overlapping or time-variant photographs with micrometer accuracy.

### Imaging quality of photogrammetric systems

A project is being conducted under the joint sponsorship of the U.S. Geological Survey and the National Research Council, National Academy of Sciences, to evaluate the elements which affect the image quality of systems for mapping.

Specially designed ground targets were constructed and laid out in a special array adjacent to the U.S. Army Photographic Test Range at Fort Huachuca, Ariz. The targets were photographed from 6,000, 12,000, and 24,000 feet with several camera-film-filter combinations, involving a Wild RC-8 camera (6-inch focal length), a Zeiss RMK 30/23 camera (12-inch focal length), and four types of Kodak aerial film. All the films were commercially processed under rigidly controlled conditions.

The same camera-film-filter combinations used in the aerial exposures were used to photograph collimator targets in the laboratory. The collimator targets were designed and fabricated to simulate the ground targets. The laboratory films were also processed under controlled conditions.

The data extraction phase of the research is currently underway. A Joyce-Loebl microdensitometer is being used to produce density traces of the target imagery, and a Mann monocomparator is being used to obtain precise dimensional measurements of images. Computer programs were developed for analyzing the data, and all programs are currently functioning.

### Film diapositives

The use of film instead of glass plates for stereoplotter diapositives is economical and saves storage space. However techniques for maintaining the geometry of images projected from film have not been fully developed. During the year, two experimental projects were conducted to evaluate the performance of equipment with film diapositives. In a Kelsh plotter equipped with experimental vacuum-frame plateholders, test models with film diapositives in black and white and color were found to be geometrically sound.

In another test, map data were drawn with a Wild B8 stereoplotter from black-and-white film and glass-plate diapositives on a selected 7½-minute quadrangle. Aerotriangulation was performed by semianalytical techniques, first with glass diapositives and then with film diapositives. The horizontal closures on control for the aerotriangulation solution were found to be about the same for both types of diapositives. Vertical elevations established in the field were withheld from the compiler during stereocompilation and later used to test the vertical accuracy of the map. The results were considered acceptable, and the use of film dia-

positives in operations is expected to increase if tests continue to be favorable.

## CARTOGRAPHY

### Orthophotomapping techniques

The continuing program of research and development in orthophotomapping techniques is showing significant results with the authorization to begin production of more than 200 orthophotomaps this fiscal year. Although a few of these maps will be experimental editions, most will be published as standard editions instead of traditional line maps. Research to further the development and application of techniques for orthophotomapping of various urban and rural areas indicated that areas of low population density can be adequately portrayed on orthophotomaps at 1:24,000 scale, but that urban areas require a scale of 1:12,000 or larger.

The availability of high-altitude photographs from commercial sources makes it possible to simplify the production of orthophotographs. Careful planning and photography can place selected exposures directly over the centers of 7½-minute quadrangles, so that the entire area of each quadrangle is captured on a single photograph. This eliminates the tedious and exacting task of mosaicking, with associated problems of tonal balance and join lines. Moreover, if the quadrangle contains extensive areas of water, a single photograph presents the consistent appearance of reflection and wave patterns obtained at a single instant in time.

Another result of obtaining the complete image of a quadrangle on one photograph is a new product, the orthophotoquad, which has been accepted as an official interim map publication. Orthophotoquads, at 1:24,000 scale, provide rapid coverage of unmapped or inadequately mapped areas until conventional topographic maps can be produced. In keeping with the interim nature of orthophotoquads, only a border with geographic and grid data is added, plus the usual marginal legends. No cartographic enhancement or color separation is applied.

### Storage and retrieval of geographic names

An automatic data processing system of storing geographic names and associated information was set up with the immediate objective of using stored data, the computer, and the typesetter in preparing printer's copy for "Decision Lists of the Board on Geographic Names," beginning with the first issue of 1970. Systematic storage of all domestic names in standard format was begun. The first step, storage of names

for the State of Massachusetts is about 70 percent complete. The standard format will permit search and research of name information in many ways related to cartography, geology, geography, linguistics, hydrology, and history. Research is continuing on more effective methods of preparing the computer input and on techniques for automatically producing master copy for printing.

**Digitizing map content**

To speed up map revision, faster and more effective methods are being sought. At present, a major effort is underway to examine the utility of digitizing techniques in cartography. This effort consists of determining the most effective map symbology for digital and photomechanical techniques and testing the technical feasibility of automated system components. The objective, at the present stage of development, is to

produce a digitally generated map from color-separation materials of an existing map.

Of the several color-separation plates currently used in map reproduction, the culture (black) plate usually contains the widest variety of symbols. To reduce manual editing of digitized information to a minimum, these symbols must be separated into an efficient number of categories before being automatically scanned and digitized. The most promising means of separation is a photographic method of line-width discrimination. This method involves controlled expanding and reducing of line widths on lithographic films and combining these films and the original drawing in intermediate masking steps to produce further plates containing different categories of symbols. The several plates with categorized symbols will serve as input for digitizing. Other color-separation plates can be scanned with a minimum of preparation.

## COMPUTER TECHNOLOGY

During fiscal year 1970 the U.S. Geological Survey Computer Center expanded its facilities and made several improvements in technical support, all of which resulted in more capability and a better level of service to the users. It was a year that saw (1) major expansion in the size of the central computer to keep up with a rising demand for computation, (2) relative stability in the system software, (3) expansion of Computer Center publications activity, and (4) implementation of a new and major application for support of administrative procedures.

### Hardware improvements

With the workload of the Computer Center growing steadily, both in Washington and at the field centers, it became obvious that a substantial increase in processing capacity would be needed to satisfy requirements. The expansion was accomplished in two ways. First, the central computer's power was augmented by the addition of another 524,288 bytes of main core storage and a second IBM 2314 disk storage unit. This made it possible to increase the level of multiprogramming and resulted in a large increase in work throughput. The second major change was the speeding up of the Model 20 terminals at Denver, Colo., and Menlo Park, Calif., and the installation of faster communication facilities for these terminals. This change, in addition to the central computer expansion, resulted in greatly improved service at these centers.

The terminal network continued to grow during the year with the addition of nine new locations for the Federal Water Quality Administration and the U.S. Bureau of Commercial Fisheries. The Computer Center also installed an IBM 2780 terminal in the Department of the Interior Building as an experimental terminal for remote access to a commercial timesharing system, and to the Geological Survey system as well. This terminal has proven to be a valuable service to users in the Washington, D.C. area. It allows them to submit short jobs for execution directly and to receive their output while they wait, avoiding the time-consuming procedures set up for submitting more lengthy, production-oriented jobs. This terminal brings the total number of terminals served by the Computer Center to 19.

In a matter related to the terminals, the Computer Center exchanged its five IBM 2701 data adapters for one 2703 transmission control unit, and at the same time adopted the new binary synchronous transmission technique. These changes have resulted in faster and more reliable data transmission, the ability to further expand the terminal network, and a lowering of the overall cost.

### Software improvements

The system-software development activities of the Computer Center were mainly devoted to making local improvements in the Houston Automatic Spooling Program (HASP) program, to maintaining the software, and to solving systems problems as they arose. The most significant event of the year's activities was the implementation of Release 18 of Operating System/360 to take advantage of the additional core- and disk-storage capacity. This new operating system allows the execution of up to six programs in the system concurrently, greatly expanding the capabilities of the system and making much better use of its processing ability.

As a part of this change in the operating system, a new version of the HASP control program was implemented. Besides giving better reliability in error handling and transmission-line control, the new HASP added two important features to the remote terminal support.

One of these features, called multileaving, allows all the card readers, printers, and card punches of the terminal to operate concurrently, rather than sequentially. In practical terms, this means that it is no longer necessary to wait until a long job is printed before entering another job. Work submission and reception can occur at the same time. This feature, along with the faster speeds available, has improved the job turnaround time at these terminals considerably.

The second feature of the new HASP is remote console support. With this feature, it is now possible for the terminal operator to interrogate the system for the status of jobs submitted from his terminal and to send messages to the central console operator. This facility gives the remote operator information and control over his workload that has long been lacking.

Two new programs were added to the system library during the year. One was the new IBM LOADER program, which, like the LDR loader program, provides a faster way to compile and execute a program than that provided by the standard linkage-editor procedures. The other is a proprietary program from Applied Data Research called Autoflow. This program reads the source language statements of a FORTRAN, COBOL, PL/I, or 360 Assembly Language program and produces an annotated schematic flow chart of the program logic. This facilitates the documentation of programs under development, and can be used to help understand the logic of older programs for which there is no flow chart.

### Technical support

Besides providing programming, computer time, and related services, the Computer Center also attempts to supply the technical support and assistance that programmers and other users in the Geological Survey need to make the most effective use of the system. This is done in three ways: (1) through the programmer assistance offices, (2) through the systems support staff, and (3) through the Computer Center's publications. During the year, three new means of communication with our users were incorporated in our publications program. First, and most important, was the issuance of the "Computer Center Division User Manual." This collection of information is designed to serve as a reference work for the active computer user, and contains all the facts and examples that would be needed to run a program on the Geological Survey system. It also gives guidance and advice to the programmer working on new applications, and explains the standards which apply to jobs processed on our system.

A second type of publication for communication of technical information among our users was set up this year. This new series, called "Technical Tips," was established to provide a way for programmers and other users to pass along their experiences and discoveries and also to be an informal publications medium for computer professionals.

One kind of information flow that is often not as free as it should be is that from the users to the management of the Computer Center. To make it easier for our users to ask questions about things they do not like or understand about the way the Center is run, or about problems that they are experiencing using our services, a new feature was created in "Sysnotes," the Computer Center technical newsletter.

This feature, called "Sysline," will accept letters on technical matters from users, find the answers to the questions or points raised, take action to correct any situation that needs it, and publish the letter and the reply. Such give-and-take between the users and the Center will do much to keep it responsive to their real needs.

As a part of the general technical support offered by the Computer Center, a procedure was established to provide emergency backup of programs and files for two major applications in the case of a catastrophic failure. Under this plan, if anything happened to the computer or the files at the Geological Survey, the applications could still be run at another location using the duplicate data tapes. This kind of emergency planning is being expanded to other applications and functions.

### New applications

Two new applications were developed this year by the Computer Center staff which were especially noteworthy. One was an administrative support system called the Departmental Integrated Payroll and Personnel System (DIPS), which was based on the Geological Survey's previous Integrated Personnel and Payroll System. This new set of programs was written to meet the specifications developed by a committee representing the Geological Survey, several other Bureaus, and the Department of the Interior, with the intent that this one system could be used to process the payroll and personnel records for the whole Department.

This system is a significant development for several reasons, not the least of which is the size of the effort that went into it. The present level of implementation provides payroll services for nearly 30,000 employees, and this number will grow. In terms of workload, this application is the largest single computer system yet attempted by the Geological Survey. While it is not yet fully developed, it will become a major factor in the future of the Computer Center, and provide a source of information on departmental employees that has never been available in one place before.

In the scientific area, one of the smaller, but more significant projects that Computer Center programmers were involved in was the "Hot Pipe" problem. This project centered around the controversial proposal for an Alaskan pipeline from the North Slope of Alaska. Survey scientists, with the assistance of the Computer Center, were able to study the effects of this proposed pipeline on the environment. This very complex mathematical analysis was accomplished on an ac-



celerated basis in a short time. The computational work was documented and published in the Geological Survey Computer Contribution series.

The Computer Center has worked on other projects

involving the simulation of physical systems through the use of computers. This technique may prove to be useful to our scientists in carrying out the programs of the Geological Survey.



## PUBLICATIONS PROGRAM

Results of research and investigations by the U.S. Geological Survey are made available to the public through various reports and maps, most of which are published by the Geological Survey. Of the formal reports published by the Geological Survey, books are printed and sold by the U.S. Government Printing Office, and maps are printed and sold by the Geological Survey.

All books, maps (exclusive of topographic quadrangle maps), and related publications published by the Geological Survey are listed in "Publications of the Geological Survey, 1879-1961," and in yearly supplements that keep the catalog up to date. New publications (including topographic quadrangle maps) are announced each month in "New Publications of the Geological Survey." All these lists of publications are free upon request to the U.S. GEOLOGICAL SURVEY, WASHINGTON, D.C. 20242.

Books, maps, charts, folios, and atlases that are out of print can no longer be purchased from any official source. They may be consulted at many libraries, and some can be purchased from dealers who handle secondhand books.

### PUBLICATIONS ISSUED

During fiscal year 1970, 256 technical book publications were published (242 in fiscal year 1969). The number of maps printed was 3,900 (4,041 in fiscal year 1969), comprising some 16,876,800 copies (15,345,000 copies in 1969), as follows:

Kind of map	Fiscal year 1969	Fiscal year 1970
National Atlas pages-----		200
Topographic-----	3, 358	3, 201
Geologic and hydrologic-----	256	201
Maps for inclusion in book reports-----	149	131
Miscellaneous, and maps for other agencies---	278	167
Total-----	4, 041	3, 900

In addition, the Geological Survey printed 760 leaflets and maps of flood-prone areas.

Geological Survey maps are distributed by mail from bulk stocks at Arlington, Va., Denver, Colo., and

Fairbanks, Alaska. Over-the-counter distribution of maps is made by these and 12 other Geological Survey offices.

In addition to 78,688,600 maps and books on hand at the beginning of the year, 12,854,700 copies of new and reprinted maps and 2,416,900 copies of books (including popular-information booklets) were received into the Geological Survey's distribution system. A total of 7,428,500 copies of maps were distributed, including 556,900 index maps. Approximately 5 million copies of maps were sold, and \$1,871,461.25 was deposited to miscellaneous receipts in the U.S. Treasury (\$1,712,224.85 in fiscal year 1969).

Also during the fiscal year, the Geological Survey distributed 526,700 technical book reports, without charge and for official use, and 2,356,700 booklets, free of charge, chiefly to the general public. In addition, 183,200 copies of the monthly publications announcement and 600,000 copies of a sheet showing topographic map symbols were sent out.

The total distribution was implemented by 497,000 individual orders. The following table compares Geological Survey map and book distribution (including booklets but excluding monthly announcements and symbol sheets) during fiscal years 1969 and 1970:

Distribution points	Fiscal year 1969	Fiscal year 1970	Change (per- cent)
Eastern (Arlington, Va.)-----	5, 125, 954	5, 608, 767	+ 9
Western (Denver, Colo.)-----	3, 564, 058	4, 415, 967	+22
Alaska (Fairbanks, Alaska)---	67, 800	88, 306	+30
12 other Survey offices-----	725, 013	794, 477	+10
Total-----	9, 482, 825	10, 907, 517	+15

### HOW TO ORDER PUBLICATIONS

#### Ordering book reports

Professional papers, bulletins, water-supply papers, "Geophysical Abstracts," "Topographic Instructions," "Techniques of Water Resources Investigations," "Abstracts of North American Geology," and some miscellaneous reports can be purchased from the SUPER-

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INTENDENT OF DOCUMENTS, GOVERNMENT PRINTING OFFICE, WASHINGTON, D.C. 20402. Prepayment is required and should be made by check or money order payable to the Superintendent of Documents. Postage stamps are not accepted, and cash is sent at the sender's risk. On orders of 100 copies or more, of the same report, a 25-percent discount is allowed. Book publications of the series listed above may also be purchased on an *over-the-counter basis* from the Geological Survey Public Inquiries Offices listed on page A257.

"Geophysical Abstracts" and "Abstracts of North American Geology" are available on subscription at rates described in the Geological Survey's monthly announcement, "New Publications of the Geological Survey." A subscription to this monthly announcement—a catalog of publications (1879–1961) with annual supplements—circulars, and some miscellaneous reports may be obtained free on application to the U.S. GEOLOGICAL SURVEY, WASHINGTON, D.C. 20242.

#### Ordering maps and charts

Maps and charts, including folios and hydrologic atlases, are sold by the U.S. Geological Survey. Address *mail* orders to DISTRIBUTION SECTION, U.S. GEOLOGICAL SURVEY, 1200 SOUTH EADS STREET, ARLINGTON, VA. 22202, for maps of areas east of the Mississippi River, including Puerto Rico and the Virgin Islands, and to DISTRIBUTION SECTION, U.S. GEOLOGICAL SURVEY, FEDERAL CENTER, DENVER, COLO. 80225, for maps of areas west of the Mississippi, including Alaska, Hawaii, Louisiana, Minnesota, Guam, and American Samoa. An order for both eastern and western maps should be sent to the closer of the two distribution sections listed above. Residents of Alaska may order Alaska maps from DISTRIBUTION SECTION, U.S. GEOLOGICAL SURVEY, 310 FIRST AVENUE, FAIRBANKS, ALASKA 99701.

Prepayment is required. Remittances should be by check or money order payable to the U.S. Geological Survey. Prices are quoted in lists of publications and, for topographic maps, in indexes to topographic mapping for individual States. Prices include the cost of surface transportation. On an order amounting to \$20 or more at the list price, 20 percent discount is allowed; on an order of \$100 or more, 40 percent discount is allowed.

Maps and charts may be purchased *over the counter* at the following U.S. Geological Survey offices: 1200 South Eads Street, Arlington, Va.; 1028 General Services Building, 19th and F Streets, NW., Washington, D.C.; 1109 North Highland Street, Arlington, Va.; 900 Pine Street, Rolla, Mo.; Building 41, Federal Center, Denver, Colo.; 345 Middlefield Road, Menlo

Park, Calif.; 445 Federal Building, 709 West Ninth Street, Juneau, Alaska; 310 First Avenue, Fairbanks, Alaska; and Public Inquiries Offices listed on page A257.

Geological Survey maps are also sold by 735 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 in the monthly list "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 Geological Survey's maps.

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.

#### State surface-water and quality-of-water records

Pending resumption of publication of surface-water records and quality-of-water records in the water-supply paper series, streamflow and quality-of-water records are being released in separate annual reports that are entitled "Water Resources Data for [State]" and consist of two parts: "Part 1, Surface Water Records," and "Part 2, Water Quality Records," on the basis of State boundaries. Distribution of these basic data reports, which are free on request, is limited and is primarily for local needs. Those interested should write to the State or States for which records are needed.

#### State water-resources investigations folders

A series of 8- by 10½-inch folders entitled "Water Resources Investigations in [State]" is a project of the Water Resources Division to inform the public about its current program in the 50 States and Puerto Rico, the Virgin Islands, Guam, American Samoa, and Okinawa. As the programs change, the folders are revised. The folders are available free on request to

the U.S. GEOLOGICAL SURVEY, WASHINGTON, D.C. 20242, or to the Water Resources Division's district offices listed on pages A259-A260.

**State lists of publications on hydrology and geology**

A series of 6- by 9-inch booklets entitled "Geologic and Water-Supply Reports and Maps, [State]" provide a ready reference to these publications on a State basis. The booklets, which also list libraries in the subject State where Survey reports and maps may be consulted, are available free on request to the U.S. GEOLOGICAL SURVEY, WASHINGTON, D.C. 20242.

**Open-file reports**

Open-file reports include unpublished manuscript reports, maps, and other material made available for

public consultation and use. Arrangements can generally be made to reproduce them at private expense. The date of release and places of availability for consultation by the public are given in press releases or other forms of public announcement. In general, open-file reports are placed in one or more of the three Geological Survey libraries: 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 A257-A260, or interested State agencies. Many open-file reports are replaced later by formally printed publications.



## COOPERATORS AND OTHER FINANCIAL CONTRIBUTORS DURING FISCAL YEAR 1970

[Cooperators listed are those with whom the U.S. Geological Survey had a written agreement for fiscal cooperation in fiscal year 1970, 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
- Knolls Atomic Power Laboratory
- Los Alamos Scientific Laboratory
- National Accelerator Laboratory
- National Reactor Testing Station
- Nevada Operations Office
- Oak Ridge Operations
- Portsmouth Area 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
- Andersen Air Force Base
- Cambridge Research Laboratory
- Norton Air Force Base
- Special Weapons Center
- Vandenberg Air Force Base
- Warner Robins Air Force Base

##### Department of the Army :

- Army Research Office
- Corps of Engineers
- Fort Bragg
- Pueblo Army Depot
- Rocky Mountain Arsenal
- White Sands Missile Range
- Yuma Proving Grounds

##### Department of Defense :

- Advanced Research Projects Agency
- Defense Atomic Support Agency
- Defense Intelligence 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 Commercial Fisheries
- Bureau of Indian Affairs
- Bureau of Land Management

##### Department of the Interior—Continued

- Bureau of Mines
- Bureau of Reclamation
- Bureau of Sport Fisheries and Wildlife
- Federal Water Quality Administration
- National Park Service
- Office of Saline Water
- Office of Water Resources Research

##### Department of Justice

##### Department of the Navy :

- Marine Corps
- Naval Oceanographic Office
- Naval Weapons Center
- Office of Naval Petroleum and Oil Shale Reserves
- Office of Naval Research

##### Department of State :

- International Boundary and Water Commission
- International Joint Commission

##### Department of the Treasury, Bureau of Customs

##### Department of Transportation, Coast Guard

##### Environmental Science Services Administration

##### Federal Aviation Administration

##### National Aeronautics and Space Administration

##### National Science Foundation

##### Office of Emergency Preparedness

##### Tennessee Valley Authority

##### Veterans Administration

### STATE, COUNTY, AND LOCAL COOPERATORS

##### Alabama :

- Alabama Department of Conservation
- Alabama Highway Department
- City of Mobile
- Geological Survey of Alabama

##### Alaska :

- Alaska Department of Fish and Game
- Alaska Department of Health and Welfare
- Alaska Department of Highways
- Alaska Department of Natural Resources
- City of Anchorage
- City of Kenai
- City of Petersburg
- 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  
 Board of Supervisors, County of San Benito  
 Bolinas Harbor District  
 California Department of Conservation, Division of Mines  
 and Geology  
 California Department of Fish and Game  
 California Department of Navigation and Ocean Develop-  
 ment  
 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 Conserva-  
 tion District  
 County of Marin  
 County of Sacramento  
 County of San Diego  
 County of San Mateo  
 County of Ventura, Flood Control District  
 Desert Water Agency  
 East Bay Municipal Utility District  
 Georgetown Divide Public Utility District  
 Imperial Irrigation District  
 Indian Wells Valley County Water District  
 Lake County Flood Control and Water Conservation Dis-  
 trict  
 Los Angeles County, Department of County Engineers  
 Metropolitan Water District of Southern California  
 Mojave Water Agency  
 Montecito County Water District  
 Monterey County Flood Control District  
 Newhall County Water District

## California—Continued

Orange County Flood Control District  
 Orange County Water District  
 Paradise Irrigation District  
 Ridgecrest County Flood Control and Water Conservation  
 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 Conser-  
 vation 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  
 Shasta County Water Agency  
 Siskiyou County Flood Control and Water Conservation  
 District  
 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  
 Westlands Water District  
 Woodbridge Irrigation 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  
 Southeastern Colorado Water Conservancy District  
 State Department of Highways, Division of Highways

## Connecticut :

City of Hartford, Department of Public Works  
 City of New Britain, Board of Water Commissioners  
 City of Torrington  
 Connecticut Geological and Natural History Survey  
 Connecticut State Water Resources Commission  
 Department of Agriculture and Natural Resources  
 Department of Transportation  
 Greater Hartford Flood Commission

## District of Columbia :

Department of Sanitary Engineering

## Delaware :

Delaware Geological Survey, University of Delaware  
 Delaware Highway Department

**Florida :**

Broward County  
 Bureau of Geology  
 Central and Southern Florida Flood Control District  
 City of Boca Raton  
 City of Dania  
 City of Fort Lauderdale  
 City of Hallandale  
 City of Miami, Department of Water and Sewers  
 City of Miami Beach  
 City of Naples  
 City of Perry  
 City of Pompano Beach  
 City of Tallahassee  
 Collier County  
 Dade County  
 Dade County Port Authority  
 Department of Natural Resources  
 Department of Transportation  
 East Central Florida Regional Planning Council  
 Florida Department of Transportation  
 Florida Division of Parks and Recreation  
 Hillsborough County  
 Orange County  
 Palm Beach County  
 Polk County  
 Reedy Creek Improvement District  
 Southwest Florida Water Management District  
 Suwanee River Authority  
 Trustees of the Internal Improvement Trust Fund  
 West Coast Inland Navigation District

**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  
 Honolulu Board of Water Supply  
 State Department of Land and Natural Resources, Division of Water and Land Development

**Idaho :**

Idaho Bureau of Mines and Geology  
 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 :  
     Geological Survey Division  
     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  
 City of Fort Dodge  
 City of Iowa City  
 Iowa Geological Survey  
 Iowa State Conservation Commission  
 Iowa State Highway Commission, Highway Research Board  
 Iowa State University  
 Iowa State University, Agricultural and Home Economics Experiment Station  
 Lynn County.  
 University of Iowa, Institute of Hydraulic Research

**Kansas :**

City of Wichita  
 Kansas State Board of Agriculture  
 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  
 University of Kentucky Research Foundation

**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  
     State Water Resources Commission

**Minnesota :**

Metropolitan Council of the Twin Cities Area  
 Minnesota Department of Administration, Minnesota Geological Survey  
 Minnesota Department of Conservation, Division of Waters  
 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 Board of Water Commissioners  
 Mississippi Geological Survey  
 Mississippi Research and Development Center  
 Mississippi State Highway Department  
 Mississippi State University  
 Pearl River Basin Development District  
 Pearl River Valley Water Supply District  
 Washington County Board of Supervisors

## Missouri :

City of Kansas City  
 City of Springfield Sanitation  
 City of Springfield Utilities  
 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 Department of Conservation, Fisheries Division  
 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 :

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  
 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 Environmental Protection :  
     Division of Fish and Game  
     Division of Water Policy and Supply  
 North Jersey District Water Supply Commission  
 Passaic Valley Water Commission  
 Water Resources Research Institute

## New Mexico :

Albuquerque Metropolitan Arroyo Flood Control Authority  
 City of Carlsbad  
 City of Gallup  
 Costilla Creek Compact Commission  
 Interstate Stream Commission  
 New Mexico State Engineer  
 New Mexico State Highway Commission  
 Pecos River Commission  
 Rio Grande Compact Commission  
 State Bureau of Mines and Mineral Resources

## 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 Legislature  
 County of Westchester, Department of Public Works  
 Department of Conservation, Division of Water Resources  
 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  
 State Department of Health  
 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 Morganton  
 City of Winston-Salem  
 North Carolina Department of Conservation and Development, Division of Mineral Resources  
 North Carolina Department of Water and Air Resources :  
     Division of Ground Water  
     Division of Planning  
     Division of Water Pollution Control  
 State Highway Commission  
 Town of Lenoir  
 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—Continued

Ohio Department of Natural Resources, Division of Water  
Ohio River Valley Water Sanitation Commission

## Oklahoma :

City of Oklahoma City, Water Department  
Grand River Dam Authority  
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  
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  
Jackson County  
Lane County, Board of County Commissioners  
Multnomah County  
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 Water Resources Authority  
City of Bethlehem  
City of Easton  
City of Philadelphia  
City of Philadelphia, Department of Public Safety  
Delaware River Master  
Delaware Valley Regional Planning Commission of Philadelphia  
Lehigh County Soil and Water Conservation District  
Pennsylvania Department of Agriculture, State Soil and Water Conservation Commission  
Pennsylvania Department of Forests and Waters  
Pennsylvania Department of Highways  
Pennsylvania Department of Mines and Mineral Industries  
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 Harbors and Rivers  
Department of Public Works, Division of Roads and Bridges  
State Water Resources Board

## South Carolina :

City of Spartanburg  
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 Department of Health  
South Dakota State Water Resources Commission

## Tennessee :

City of Chattanooga  
City of Lawrenceburg  
City of Oak Ridge  
Memphis Light, Gas, and Water Division  
Metropolitan 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 Brady  
City of Dallas  
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 Fish and Game  
Division of Oil and Gas Conservation  
Division of Water Resources  
Division of Water Rights  
Utah Geological and Mineralogical Survey

## 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  
 Municipality of Metropolitan Seattle  
 Port of Seattle  
 Public Utility District No. 1 of Cowlitz County  
 Washington State Department of Fisheries  
 Washington State Department of Game  
 Washington State Department of Highways  
 Washington State Department of Natural Resources, Division of Mines and Geology  
 Washington State Department of Water Resources  
 Washington State Water Pollution Control Commission  
 Western Washington State College

**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

**Wisconsin—Continued**

State Department of Transportation, Division of Highways  
 The University of Wisconsin, Geological and Natural History Survey

**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, 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 NW., 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

<i>Location</i>	<i>Official in charge and telephone number</i>	<i>Address</i>
Alaska, Anchorage 99501.....	Margaret I. Erwin (277-0577).....	108 Skyline Bldg., 508 2d Ave.
California, Los Angeles 90012.....	Lucy E. Birdsall (213 688-2850).....	7638 Federal Bldg., 300 N. Los Angeles St.
San Francisco 94111.....	Jean V. Molleskog (415 556-5627).....	504 Custom House, 555 Battery St.
Colorado, Denver 80202.....	Lorene C. Young (303 297-4169).....	1012 Federal Bldg., 1961 Stout St.
Texas, Dallas 75202.....	Mary E. Reid (214 749-3230).....	602 Thomas Bldg., 1314 Wood St.
Utah, Salt Lake City 84111.....	Maurine Clifford (801 524-5652).....	8102 Federal Bldg., 125 S. State St.
Washington, Spokane 99201.....	Eva M. Raymond (509 838-4611, ext. 111).....	678 U.S. Court House, West 920 Riverside Ave.

### SELECTED FIELD OFFICES IN THE UNITED STATES AND PUERTO RICO

[Temporary offices not included; list current as of July 1, 1970. Correspondence to the following offices should be addressed to the Post Office Box, if one is given]

### COMPUTER CENTER DIVISION

<i>Location</i>	<i>Official in charge and telephone number</i>	<i>Address</i>
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.....	Keith M. Beardsley (314 364-6985).....	P.O. Box 41.

### 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]

<i>Location</i>	<i>Official in charge and telephone number</i>	<i>Address</i>
Alaska, Anchorage 99501.....	Leo H. Saarela (m) (907 277-0578), Alexander A. Wanek (c) (907 277-0570), W. J. Linton (o) (907 277-0579).	P.O. Box 259; 208-214 Skyline Bldg., 218 E St.
California, Los Angeles 90012.....	William C. Gere (c) (213 688-2746), D. W. Solanas (o) (213 688-2846).	7744 Federal Bldg., 300 N. Los Angeles St.
Sacramento 95825.....	Kenneth W. Sax (w) (916 481-2219).....	W-2231 Federal Bldg., 2800 Cottage Way.
Bakersfield 93301.....	Harry Lee Wolf (o), vacant (c) (805 323-7676).....	309 Federal Bldg., 800 Truxtun Ave.
Menlo Park 94025.....	Donal F. Ziehl (m) (415 325-6761, ext. 563, 564), Larry Godwin (c) (415 325-2563).	345 Middlefield Rd.
Santa Barbara, 93101.....	Harry T. Cypher (o) (805 963-3305).....	209 Post Office Bldg., 836 Anacapa St.
Colorado, Denver 80202.....	Edward R. Haymaker (o) (303 297-4752), John P. Storrs (m) (303 297-4751).	6041 and 6029 Federal Bldg., 1961 Stout St.
Denver 80225.....	George H. Horn (c) (303 233-8168).....	Bldg. 25, Federal Center.
Denver 80202.....	William C. Senkpiel (w) (303 297-4753), Robert G. Dickinson (c) (303 297-4751).	6023 and 6025 Federal Bldg., 1961 Stout St.
Durango 81302.....	Jerry W. Long (o) (303 247-5144).....	P.O. Box 1809; Jarvis Bldg., 125 W. 10th St.
Louisiana, Lafayette 70501.....	George Kinsel (o) (318 232-6037).....	P.O. Box 52289; 239 Bendel Road.
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.
Shreveport 71101.....	Thomas E. Godfrey (o) (318 425-6355).....	201 Oil and Gas Bldg., 323 Market St.
Montana, Billings 59103.....	Albert F. Czarnowsky (m), Virgil L. Pauli (o) (406 245-6711, ext. 6368), Elmer M. Schell (c) (406 245-6367).	P.O. Box 2550; 217 Post Office Bldg.
Great Falls 59401.....	Andrew F. Bateman (c) (406 761-3314).....	P.O. Box 2265; 510 1st Ave. N.

## U.S. GEOLOGICAL SURVEY OFFICES

<i>Location</i>	<i>Official in charge and telephone number</i>	<i>Address</i>
New Mexico, Artesia 88210.....	James A. Knauff (o) (505 746-4841).....	Drawer U; 210 Carper Bldg., 105 S. 4th St.
Carlsbad 88220.....	Robert S. Fulton (m), James S. Hinds (c) (505 885-6454).	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.....	J. A. Anderson (o) (505 622-9857), Donald M. Van Sickle (c) (505 622-9857).	Drawer 1857; Federal Bldg., and U.S. Courthouse, Richardson Ave. at 5th St.
Oklahoma, McAlester 74501.....	Alex 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) (405 236-2278).....	5321 Federal Courthouse and Office Bldg., 220 NW. 4th St.
Tulsa 74103.....	Edward L. Johnson (c) (918 584-7638), N. Orvis Frederick (o) (918 584-7632).	4562 New Federal Bldg., 333 W. 4th St.
Oregon, Portland 97208.....	Jesse L. Colbert (w) (503 234-4796).....	P.O. Box 3202; 830 NE. Holladay St.
Utah, Salt Lake City 84111.....	Ernest Blessing (m) (801 524-5646), Rodney A. Smith (o) (801 524-5650), Howard F. Albee (c) (801 524-5643).	8402, 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) (307 265-3406), William H. Laraway (c) (306 265-3270).	P.O. Box 400; 305 Federal Bldg.
Newcastle 82701.....	Glenn E. Worden (o) (307 746-4554).....	P.O. Box 219; 214 W. Main St.
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

<i>Location</i>	<i>Official in charge and telephone number</i>	<i>Address</i>
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).....	601 E. Cedar Ave.
California, La Jolla 92037.....	John D. Strobell (602 774-5261, ext. 1463).....	121 E. Birch Ave.
Hawaii, Hawaii National Park 96718.....	George W. Moore (714 453-2820, ext. 341).....	P.O. Box 271; 8604 La Jolla Dr.
Kentucky, Lexington 40508.....	Donald W. Peterson (967-7485).....	Hawaiian Volcano Observatory.
Massachusetts, Boston 02110.....	Wilds W. O'ive (606 252-2312, ext. 2552).....	710 W. High St.
Woods Hole 02543.....	Lincoln R. Page (617 223-7202).....	80 Broad St.
New Mexico, Albuquerque 87106.....	John S. Schlee (617 548-8533).....	U.S. Geological Survey, Woods Hole Oceanographic Institution.
Ohio, Columbus 43210.....	Charles B. Read (505 843-2843).....	P.O. Box 4083; Station A, Geology Bldg., Univ. of New Mexico.
Puerto Rico, San Juan 00936.....	James M. Schopf (614 294-1801).....	Orton Hall, Ohio State Univ., 155 S. Oval Dr.
Santurce 00910.....	John M. Aaron (809 766-5340).....	GPO Drawer 2230.
Tennessee, Knoxville.....	Dennis P. Cox (809 725-6550, ext. 259).....	Department of Public Works, Natural Resources Laboratory, P.O. Box 8218.
Texas, Austin 78701.....	Robert A. Laurence (615 524-4011, ext. 4268).....	301 W. Cumberland Ave.
Corpus Christi 78411.....	D. Hoyer Eargle (512 476-6580).....	801 Federal Center.
Utah, Salt Lake City 84111.....	Louis E. Garrison (512 883-5293).....	P.O. Box 6732; Univ. of Corpus Christi.
Washington, Spokane 99204.....	Lowell S. Hilpert (801 524-5640).....	8426 Federal Bldg.
Wisconsin, Madison 53706.....	Albert E. Weissenborn (509 838-4611, ext. 3121).	South 157 Howard St.
Wyoming, Laramie 82071.....	Carl E. Dutton (608 262-1234, ext. 1854).....	222 Science Hall, Univ. of Wisconsin.
	J. David Love (307 Franklin 5-4495).....	Box 3007, Univ. Station, Geology Hall, Univ. of Wyoming.

## TOPOGRAPHIC DIVISION

<i>Location</i>	<i>Engineer in charge and telephone number</i>	<i>Address</i>
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.....	James S. Crabtree (703 521-6555).....	1109 N. Highland St.



**WATER RESOURCES DIVISION****REGIONAL OFFICES**

<i>Location</i>	<i>Official in charge and telephone number</i>	<i>Address</i>
<b>Atlantic Coast Region:</b>		
Arlington, Va. 22209	George E. Ferguson, Regional Hydrologist (202 343-8841).	Rm. 317 George Washington Bldg., Arlington Towers, 1011 Arlington Blvd.
<b>Midcontinent Region:</b>		
St. Louis, Mo. 63141	Elwood R. Leeson, Regional Hydrologist (314 268-7224).	Suite 212, West Port 104 Building, 2222 Schuetz Rd.
<b>Rocky Mountain Region:</b>		
Denver, Colo. 80225	Thad G. McLaughlin, Regional Hydrologist (303 233-6701).	Bldg. 25, Federal Center.
<b>Pacific Coast Region:</b>		
Menlo Park, Calif. 94025	Warren W. Hastings, Regional Hydrologist (415 325-6761, ext. 337, 339, 487).	345 Middlefield Rd.

**DISTRICT OFFICES**

<i>Location</i>	<i>Official in charge and telephone number</i>	<i>Address</i>
Alabama, Tuscaloosa 35486	William L. Broadhurst (205 345-8226)	P.O. Box V; Oil and Gas Board Bldg.; 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, 6392, 6393).	P.O. Box 4070.
Arkansas, Little Rock 72201	Richard T. Sniogocki (501 372-5270)	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 (303 233-8621)	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)	P.O. Box 2315.
Georgia, Atlanta 30309	John R. George (404 526-5663, 5664)	Rm. 301, 900 Peachtree St., NE.
Hawaii, Honolulu 96814	Mearle M. Miller (546-5692, 5693, 5694, 5695).	Rm. 330, First Insurance Bldg., 1100 Ward Ave.
Idaho, Boise 83702	Willis L. Burnham (208 342-2711, ext. 538)	Rm. 365, Federal Bldg., 550 W. Fourth St.
Illinois, Champaign 61820	William D. Mitchell (217 359-3918)	P.O. Box 1026; 605 N. Neil St.
Indiana, Indianapolis 46204	Malcolm D. Hale (317 633-7398)	Rm. 516, 611 N. Park Ave.
Iowa, Iowa City 52240	Sulo W. Wiitala (319 338-0581, ext. 475)	Suite F, 1041 Arthur St.
Kansas, Lawrence 66044	Charles W. Lane (913 864-4321)	P.O. Box 768; USGS Bldg., West of 19th and Iowa Sts.
Kentucky, Louisville 40202	Floyd F. Schrader (502 582-5241, 5242, 5243)	Rm. 572, Federal Bldg., 600 Federal Place.
Louisiana, Baton Rouge 70806	Rex R. Meyer (504 348-4281)	Rm. 215, Prudential Bldg., 6554 Florida Blvd.
Maine, Augusta 04330	Gordon S. Hayes (207 289-3484)	Vickery-Hill Bldg., Court St.
Maryland, Towson 21204	Walter F. White, Jr. (301 828-7460)	724 York 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.
Minnesota, St. Paul 55101	Charles R. Collier (612 725-7841, 7842)	Rm. 1002, New 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)	222 E. Washington 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.
New Mexico, Albuquerque 87106	William E. Hale (505 247-2500)	P.O. Box 4369; Geology Bldg., Univ. of New Mexico.
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 (919 828-9031, ext. 126)	P.O. Box 2857; 4th Floor, Federal Bldg.

<i>Location</i>	<i>Official in charge and telephone number</i>	<i>Address</i>
North Dakota, Bismarck 58501.....	Robert C. Williams (701 255-4011, ext. 227, 228).	P.O. Box 778; Rm. 348, New Federal Bldg. 3d St. and Rosser Ave.
Ohio, Columbus 43212.....	John J. Molloy (614 469-5553, 5554).....	975 W. 3d Ave.
Oklahoma, Oklahoma City 73102.....	John W. Odell (405 231-4256, 4257, 4258, 4259).	Room 4301, Federal Bldg. and U.S. Court House, 200 NW. 4th St.
Oregon, Portland 97208.....	Stanley F. Kapustka (503 234-3361, ext. 1976, 1977, 1978).	P.O. Box 3202; 830 NE. Holladay St.
Pennsylvania, Harrisburg 17108.....	Norman H. Beamer (717 782-3468).....	P.O. Box 1107; 4th Floor, 228 Walnut St.
Puerto Rico, San Juan 00934.....	Dean B. Bogart (809 783-4660, 4469, 4788)....	2d Floor, Bldg. 653 at Ft. Buchanan, Bldg. 652, U.S. Naval Station Annex.
Rhode Island.....	Charles E. Knox (617 223-2822).....	See Massachusetts District Office.
South Carolina, Columbia 29204.....	John S. Stallings (803 253-8371, ext. 401).....	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 (615 242-8321, ext. 5424)....	Rm. 144, Federal Bldg.
Texas, Austin 78701.....	Trigg Twichell (512 475-5766, 5767, 5768).....	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 (703 649-2427).....	200 W. Grace St.
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 (307 778-2317, 2331, 2414, 2474).	P.O. Box 2087; 215 E. 8th Ave.

## OFFICES IN OTHER COUNTRIES

### GEOLOGIC DIVISION

<i>Location</i>	<i>Official in charge</i>	<i>Address</i>
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.
Goiania.....		U.S. Geological Survey, USAID/Rio de Janeiro/ENRG, 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 Bogota, c/o American Embassy Bogotá, Colombia.
Indonesia, Bandung.....	Montis R. Klepper.....	U.S. Geological Survey, c/o American Embassy, USAID/ENGR, APO San Francisco, Calif. 96356.
Liberia, Monrovia.....	Warren L. Coonrad.....	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

<i>Location</i>	<i>Official in charge</i>	<i>Address</i>
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.....	Maurice J. Mundorff.....	U.S. AID/Nairobi, U.S. Dept. of State, Washington, D.C. 20521.
Korea, Seoul.....	Joseph T. Callahan.....	U.S. Geological Survey, USOM/BUREC/AID, APO San Francisco, Calif. 96301.
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.
Zambia, Lusaka.....	Laurence E. Bidwell.....	USGS/Lusaka, 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 1970 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. A257–A260, for addresses). Inquiries regarding projects for which no address is given in the list of offices should be directed to the appropriate Division of the Geological Survey, Washington, D.C. 20242. The lowercase letter following the name of the project leader shows the Division technical responsibility: c, Conservation Division; w, Water Resources Division; no letter, Geologic Division.

The projects are classified by principal topic. Most geologic-mapping projects involve special studies of stratigraphy, petrology, geologic structure, or mineral deposits, but are listed only under "Geologic Mapping" unless a special topic or commodity is the primary justification for the project. A reader interested in investigations of volcanology, for example, should look under the heading "Geologic Mapping" for projects in areas of volcanic rocks, as well as under the heading "Volcanology." Likewise, most water-resources investigations involve special studies of several aspects of hydrology and geology, but are listed only under "Water Resources" unless a special topic—such as floods or sedimentation—is the primary justification for the project.

Areal geologic mapping is subdivided into mapping at scales smaller than 1 inch to 1 mile (for example, 1:250,000), and mapping at scales of 1 inch to 1 mile, or larger (for example, 1:62,500; 1:24,000).

**Abstracts.** See Bibliographies and abstracts.

### **Analytical chemistry:**

- Activation analysis (J. Rowe, W)
  - Analytical methods—water chemistry (M. W. Skougstad, w, D)
  - Analytical services and research (I. May, W; C. Huffman, Jr., D; C. O. Ingamells, M)
  - Instrumentation (J. F. Abell, W)
  - 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 (G. Stratton, 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)
  - Trace analysis methods, research (F. N. Ward, D)
  - Ultratrace analysis (H. T. Millard, D)
  - Water analysis—Methods manual (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)
- Colorado, Kit Carson County (W. E. Hofstra, w, Denver)
- Florida:
  - Floridan aquifer, Orange County (W. F. Lichtler, w, Winter Park)
  - Floridan aquifer, west-central area (W. C. Sinclair, w, Tampa)
  - Injection of wastes in deep wells (D. A. Goolsby, w, Ocala)
- Minnesota:
  - Fractured carbonate rock—Minneapolis-St. Paul area (H. O. Reeder, w, St. Paul)
- New York, 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)

#### **Base metals:**

- Missouri, iron (P. W. Guild, W)
- See also base-metal names.

#### **Bibliographies and abstracts:**

- Annotated bibliography on hydrology and sedimentation, 1966-68—United States and Canada, for Water Resources Council (N. M. Baker, w, W)
- Annotated bibliography of sedimentation in coastal bodies of water (D. D. Carstea, W. L. Haushild, w, W)

**Bibliographies and abstracts--Continued**

- Annotated bibliography of subsurface waste disposal by means of wells (D. R. Rima, w, W)
- Geophysical abstracts (J. W. Clarke, W)
- Hydrology of the United States and Canada, bibliography (N. M. Baker, w, W)
- Lunar bibliography (J. H. Freeberg, M)
- North American geology, bibliography (J. W. Clarke, W)
- Remote-sensing bibliography for earth resources, indexed, with notation of content (R. K. Llaverias, w, W)
- Sedimentation in coastal bodies of water, annotated, indexed (D. D. Carstea, w, W)
- Vanadium, geology and resources, bibliography (J. P. Ohl, D)
- Water-resources selected abstracts, bibliography, index, input to Water Resources Scientific Information Center (J. W. Lang, w, W)

**Borates:**

- Borate marshes, California, Nevada, and Oregon (W. C. Smith, M)

**California:**

- Furnace Creek area (J. F. McAllister, M)
- Searles Lake area (G. I. Smith, M)

**Chromite. See Ferro-alloy metals.****Clays:**

- Appalachia, northern part (J. W. Hosterman, Beltsville, Md.)
- Florida and Georgia, Attapulgus-Thomasville fuller's earth deposits (S. H. Patterson, Beltsville, Md.)

**Coal:**

- Resources of the United States (P. Averitt, D)

**Alaska:**

- Bering River coal field (A. A. Wanek, c, Anchorage)
- Cape Beaufort-Corwin Bluff coal field (A. A. Wanek, c, Anchorage)
- Kukpowruk River coal field (A. A. Wanek, c, Anchorage)
- Nenana (C. Wahrhaftig, M)

**Arizona:**

- Cummings Mesa quadrangle (F. Peterson, c, D)
- Gunsight Butte SE and SW quadrangles (F. Peterson, c, D)
- Nipple Butte 15-minute quadrangle, (H. A. Waldrop, c, D)

**California:**

- Hernandez Valley quadrangle (W. C. Gere, c, Los Angeles, Calif.)
- Priest Valley SE quadrangle (W. C. Gere, c, Los Angeles)

**Colorado:**

- Buckhorn Lakes quadrangle (R. G. Dickinson, c, D)
- Courthouse Mountain quadrangle (R. G. Dickinson, c, D)
- Kremmling quadrangle (G. A. Izett, c, D)
- Mellen Hill quadrangle (H. L. Cullins, c, D)
- Peoria quadrangle (P. E. Soister, c, D)
- Rangely 7½-minute and Rangely NE quadrangle (H. L. Cullins, c, Meterie, La.)
- Savery quadrangle (C. S. V. Barclay, c, D)
- Strasburg NW and SW quadrangles (P. E. Soister, c, D)
- Washboard Rock quadrangle (R. G. Dickinson, c, D)
- Watkins and Watkins SE quadrangles (P. E. Soister, c, D)

**Montana:**

- Black John Coulee quadrangle (G. D. Mowat, c, Billings)
- Hardy quadrangle (K. S. Soward, c, Great Falls)
- Jordan 2 NE and SE quadrangles (G. D. Mowat, c, Billings)
- Rocky Reef quadrangle (K. S. Soward, c, Great Falls)
- Nevada, Coaldale area (L. H. Godwin, c, M)

**Coal--Continued****New Mexico:**

- Fruitland Formation (J. E. Fassett, c, Farmington)
- Gallup West quadrangle (J. E. Fassett, c, Farmington)
- Manuelito quadrangle (J. E. Fassett, c, Farmington)
- Samson Lake quadrangle (J. E. Fassett, c, Farmington)
- Twin Butte quadrangle (J. E. Fassett, c, Farmington)
- Western Raton field (C. L. Pillmore, D)

**North Dakota:**

- Clark Butte 15-minute quadrangle (G. D. Mowat, c, Billings, Mont.)
- Dengate quadrangle (C. S. V. Barclay, c, D)
- Glen Ullin quadrangle (C. S. V. Barclay, c, D)
- Heart Butte and Heart Butte NW quadrangles (E. V. Stephens, c, D)
- New Salem quadrangle (H. L. Smith, c, D)
- North Almont quadrangle (H. L. Smith, c, D)
- White Butte 15-minute quadrangle (K. S. Soward, c, Great Falls, Mont.)

**Pennsylvania:**

- Anthracite region, flood control (M. J. Bergin, W)
- Claysville-Avella area (S. P. Schweinfurth, W)
- Mather-Garards Fort area (B. H. Kent, D)
- Southern anthracite field (G. H. Wood, Jr., W)
- Waynesburg-Oak Forest area (J. B. Roen, Beltsville, Md.)
- Western Middle anthracite field (H. Arndt, D)

**Utah:**

- Canaan Creek quadrangle (H. D. Zeller, c, D)
- Canaan Peak quadrangle (W. E. Bowers, c, D)
- Carcass Canyon quadrangle (H. D. Zeller, c, D)
- Collet Top quadrangle (H. D. Zeller, c, D)
- Cummings Mesa quadrangle (F. Peterson, c, D)
- Dave Canyon quadrangle (H. D. Zeller, c, D)
- Death Ridge quadrangle (H. D. Zeller, c, D)
- Gilbert Peak 1 NE quadrangle (E. M. Schell, c, Billings, Mont.)
- Griffin Point quadrangle (W. E. Bowers, c, D)
- Gunsight Butte 15-minute quadrangle (F. Peterson, c, D)
- Henrieville quadrangle (W. E. Bowers, c, D)
- Jessen Butte quadrangle (E. M. Schell, c, Billings, Mont.)
- Nipple Butte 15-minute quadrangle, (H. A. Waldrop, c, D)
- Phil Pico Mountain quadrangle (E. M. Schell, c, Billings, Mont.)
- Pine Lake quadrangle (W. E. Bowers, c, D)
- Seep Flat quadrangle (E. V. Stephens, c, D)
- Upper Valley quadrangle (W. E. Bowers, c, D)
- Wide Hollow Reservoir quadrangle (E. V. Stephens, c, D)
- Virginia, Pocahontas coal beds (K. J. Englund, W)
- West Virginia, low-sulfur resources (K. J. Englund, W)

**Wyoming:**

- Bailey Lake quadrangle (M. L. Schroeder, c, D)
- Browns Hill quadrangle (C. S. V. Barclay, c, D)
- Bull Creek quadrangle (M. L. Schroeder, c, D)
- Cache Creek quadrangle (D. A. Jobin, c, D)
- Camp Davis quadrangle (D. A. Jobin, c, D)
- Deer Creek quadrangle (D. A. Jobin, c, D)
- Ferris quadrangle (R. L. Rioux, c, W)
- Ferry Peak quadrangle (D. A. Jobin, c, D)
- Hoback Peak quadrangle (D. A. Jobin, c, D)
- Jackson quadrangle (H. F. Albee, c, Salt Lake City, Utah)
- Observation Peak quadrangle (H. F. Albee, c, Salt Lake City, Utah)
- Oil Mountain quadrangle (W. H. Laraway, c, Casper)
- Pickle Pass quadrangle (D. A. Jobin, c, D)

**Coal--Continued**

- Poison Spider quadrangle (W. H. Laraway, c, Casper)
- Reid Canyon (W. H. Laraway, c, Casper)
- Savery quadrangle (C. S. V. Barclay, c, D)
- Sheridan Pass quadrangle (W. L. Rohrer, c, D)
- Square Top Butte quadrangle (W. H. Laraway, c, Casper)
- Stewart Peak quadrangle (D. A. Jobin, c, D)
- Taylor Mountain quadrangle (M. L. Schroeder, c, D)

**Construction and terrain problems:**

- Botanical techniques for on-site investigations (H. T. Shacklette, D)
  - Deformation research (S. P. Kanizay, D)
  - Electronics instrumentation research (J. B. Bennetti, D)
  - Engineering properties of rocks and soils (T. C. Nichols, Jr., D)
  - Foreign playas (D. B. Krinsley, W)
  - Geologic effects analysis, nuclear explosives (F. A. McKeown, D)
  - Geologic environmental studies for land-use planning, California (C. M. Wentworth, Jr., M)
  - Military geology (M. A. Conti, W)
  - Mudflow studies, Washington, Oregon, Colorado (D. R. Crandell, D)
  - Reactor site investigations (H. H. Waldron, D)
  - Research on faults for land-use planning (M. G. Bonilla, M)
  - Seismicity as related to geologic parameters (R. O. Castle, M)
  - Sino-Soviet terrain atlas (J. Rachlin, W)
  - Source materials services (L. D. Bonham, W)
  - Special intelligence (M. J. Terman, W)
  - Topical geophysics (R. D. Carroll, D)
  - Water-resource development, potential applications of nuclear explosives (F. W. Stead, D)
  - Alaska:
    - Arctic engineering (R. Kachadoorian, M)
    - Supplemental test site, Amchitka and Rat Islands (F. A. McKeown, D)
  - California, San Francisco Bay sediments, engineering geology studies (D. R. Nichols, M)
  - Colorado:
    - Black Canyon of the Gunnison River (W. R. Hansen, D)
    - Straight Creek tunnel (F. T. Lee, D)
  - Massachusetts, sea-cliff erosion studies (C. A. Kaye, Boston)
  - Nevada:
    - Nevada Test Site, geophysics (R. D. Carroll, D)
    - Nevada Test Site, site studies (P. P. Orkild, D; R. E. Davis, D)
  - Utah, coal-mine bumps (F. W. Osterwald, D)
- See also* Urban geology.

**Contamination, water:**

- Distribution, source, and transport of organic pesticides in reservoir sediments (M. L. Yates, w, W)
  - Pesticide pollutants in water (R. L. Wershaw, w, D)
  - Massachusetts, ground-water contamination from highway salt (S. J. Pollock, w, Boston)
  - New Hampshire, ground-water contamination from highway salt (H. A. Whitcomb, w, Concord)
  - New York, abatement of pollution, southwestern Nassau County (N. M. Perlmutter, w, Mineola)
- See also* Analytical chemistry; Salt-water intrusion.

**Copper:**

- Arizona, Ray porphyry copper (H. R. Cornwall, M)
- Maine and New Hampshire, porphyry, with molybdenum (R. G. Schmidt, W)

**Copper--Continued****Michigan:**

- Greenland and Rockland quadrangles (J. W. Whitlow, Beltsville, Md.)
- Michigan copper district (W. S. White, Beltsville, Md.)
- Nevada, Copper Canyon deposit (T. G. Theodore, M)
- Puerto Rico (D. P. Cox, Santurce)
- Utah, Bingham Canyon district (E. W. Tooker, M)
- Crustal studies. *See* Earthquake studies; Geophysics, regional.
- Desalination, Hackensack River, vicinity of Newark, N.J. (P. W. Anderson and J. J. Murphy, w, Trenton, N.J.)

**Detergents. *See* Contamination, water.****Earthquake studies:**

- Aeromagnetic investigation for crustal studies (I. Zietz, W)
- Computer modeling (W. H. K. Lee, M)
- Crustal strain studies (R. O. Burford, M)
- Crustal studies (ARPA) (I. Zietz, W)
- Earth structure studies (J. H. Healy, M)
- Fault-zone geophysical studies (W. H. Jackson, M)
- Fault-zone tectonics (J. C. Savage, M)
- Ground motion studies (J. H. Healy, M)
- Hazard analysis:
  - Anchorage, Alaska (E. Dobrovolny, D)
  - Juneau, Alaska (R. D. Miller, D)
  - Small coastal communities (R. W. Lemke, D)
- Large Aperture Seismic Array analysis (H. M. Iyer, M)
- Project Sterling (J. H. Healy, M)
- Research on faults for land-use planning (M. G. Bonilla, M)
- Research on rock mechanics (T. C. Nichols, Jr., D)
- Seismicity as related to geologic parameters (R. O. Castle, M)
- Stress studies (C. B. Raleigh, M)

**California:**

- Basement and volcanic rock studies along San Andreas fault (D. C. Ross, M)
- Breaks along San Andreas fault (M. M. Clark, M)
- Evolution of sedimentary basins near San Andreas fault (H. C. Wagner, M)
- Geologic framework of San Andreas fault (T. W. Dibblee, Jr., M)
- Geophysical studies, San Andreas fault (J. H. Healy, M)
- Hayward-Calaveras fault zones (D. H. Radbruch, M)
- Regional tectonic analysis (R. E. Wallace, M)
- Colorado, Denver earthquake studies (D. B. Hoover, D)

**Ecology:**

- Washington, influence of stream hydraulics on anadromous fish migration and propagation (M. R. Collings, w, Tacoma)

**Engineering geologic studies. *See* Construction and terrain problems; Urban geology.****Evaporation:**

- Evaporation from lakes and reservoirs (J. S. Meyers, w, D)
- Indiana, evaporation losses from lakes (J. E. Heisel, w, Indianapolis)
- North Carolina:
  - Lake Michie, evaporation analysis (W. L. Yonts, w, Raleigh)
  - Roxboro Lake, evaporation and thermal-loading analysis (W. L. Yonts, w, Raleigh)
- See also* Hydrologic instrumentation.
- Evaporation suppression:
  - Mechanics of evaporation suppression and evaporation (G. E. Koberg, w, D)

**Evapotranspiration:**

- Hydrologic effects of vegetation modification (R. M. Myrick, w, Tucson, Ariz.)
- Use of water by saltcedar in evapotranspirometers, measured and computed by energy budget and mass transfer methods, Arizona (T. E. A. van Hylckama, w, Lubbock, Tex.)

**Arizona:**

- Phreatophyte project, Gila River (R. C. Culler, w, Tucson)
- Potential evapotranspiration loss of Agua Fria River (T. W. Anderson, w, Phoenix)
- Study of effects of vegetation manipulation on surface runoff, Sycamore Creek (H. W. Hjalmarson, w, Phoenix)
- California, root-zone conditions and plant-physiological processes as factors in phreatophyte evapotranspiration (O. M. Grosz, w, M)

**Extraterrestrial studies:****Impact investigations:**

- Experimental impact investigations (H. J. Moore, M)
- Impact metamorphism (E. C. T. Chao, W; D. J. Roddy, Flagstaff, Ariz.)

**Investigations of terrestrial analogs:**

- Bend, Oreg., volcanics (L. C. Rowan, Flagstaff, Ariz.)
- Decaturville, Mo. (T. W. Offield, Flagstaff, Ariz.)
- Explosion craters (D. J. Roddy, Flagstaff, Ariz.)
- Flynn Creek, Tenn. (D. J. Roddy, Flagstaff, Ariz.)
- Gosses Bluff, Australia, astrobleme (D. J. Milton, M)
- Lava-tube studies (K. A. Howard, M)
- Lunar Crater, Nev. (N. J. Trask, M)
- Mule Ear, Utah (D. E. Stuart-Alexander, M)
- Nunivak, Alaska (H. G. Wilshire, M)
- San Francisco volcanic field (J. F. McCauley, M)
- Sierra Madera (H. G. Wilshire, M)

**Lunar erosion mechanisms (S. A. Schumm, w, Fort Collins, Colo.)****Lunar exploration techniques:**

- Advanced systems traverse research (G. E. Ulrich, Flagstaff, Ariz.)
- Apollo geologic instruments (J. W. M'Gonigle, Flagstaff, Ariz.)
- Apollo geological methods (M. H. Hait, Jr., Flagstaff, Ariz.)
- Astrogeologic data facilities studies (D. H. Dahlem, Flagstaff, Ariz.)
- Astronaut training (A. H. Chidester, Flagstaff, Ariz.)
- Early Apollo geophysical topical studies (H. D. Ackermann, Flagstaff, Ariz.)
- Lunar materials, resources and processes (D. P. Elston, Flagstaff, Ariz.)
- Mission planning (T. N. V. Karlstrom, Flagstaff, Ariz.)
- Photoclinometry (W. T. Borgeson, Flagstaff, Ariz.)
- Photogrammetry (R. M. Batson, W. T. Borgeson, Flagstaff, Ariz.)

**Post-Apollo investigations:**

- Geologic instruments studies (G. G. Schaber, Flagstaff, Ariz.)
- Lunar geologic methods studies (D. L. Schleicher, Flagstaff, Ariz.)
- Research in geologic methods (M. R. Brock, Flagstaff, Ariz.)

**Lunar mapping:**

- Apollo site mapping (D. E. Wilhelms, M)

**Extraterrestrial studies--Continued****Lunar mapping--Continued**

- Film documentation (W. Roeder, Flagstaff, Ariz.)
- Lunar stratigraphy (D. E. Wilhelms, M)
- Lunar trafficability (L. C. Rowan, Flagstaff, Ariz.)
- Post-Apollo test site mapping (R. L. Sutton, Flagstaff, Ariz.)

**Surveyor-coordination and geologic synthesis (E. C. Morris, Flagstaff, Ariz.)****Terrain analysis (L. C. Rowan, R. J. Pike, Flagstaff, Ariz.)****Lunar remote sensing techniques:**

- Experimental photometric investigations (R. L. Wildey, Flagstaff, Ariz.)
- Experimental photometry (H. A. Pohn, H. E. Holt, Flagstaff, Ariz.)
- Lunar orbiter operations (L. C. Rowan, Flagstaff, Ariz.)
- Surveyor-photometry and photoclinometry (H. E. Holt, Flagstaff, Ariz.)

**Lunar samples, mineralogic studies (M. B. Duke, W)****Mars exploration (H. Masursky, Flagstaff, Ariz.)****Tektite and meteorite investigations:**

- Mineralogical studies (M. B. Duke, W)
- Petrology of meteorites (P. R. Brett, W)

**Ferro-alloy metals:****Chromium resource studies (T. P. Thayer, W)****Cobalt resource studies (J. S. Vhay, Spokane, Wash.)****Manganese:**

- Geology and geochemistry (D. F. Hewett, M)
- Resource studies (J. V. N. Dorr II, W)
- Zoning in epithermal deposits (R. G. Worl, D)

**Molybdenum, Maine and New Hampshire, with porphyry copper (R. G. Schmidt, W)****Molybdenum-rhenium resource studies (R. U. King, D)****Tungsten, North Carolina, Hamme district (J. E. Gair, W)****Ultramafic rocks of the Southeastern United States (D. M. Larrabee, W)****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 (H. H. Schwob, w, Iowa City)
- Kansas, characteristics of flood hydrographs (E. R. Hedman, w, Lawrence)
- Kentucky (C. H. Hannum, w, Louisville)
- Mississippi, bridge-site flood investigations (C. P. Humphreys, Jr., 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)

**Flood characteristics of streams at selected sites--Continued****Utah:**

Bridge-site investigations (G. E. Pyper, w, Salt Lake City)  
 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 (D. W. Ellis, w, Champaign)

Iowa (H. H. Schwob, 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 (John 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 (I. J. Hickenlooper, w, Nashville)

Texas (E. E. Schroeder, w, Austin)

Vermont (C. G. Johnson, Jr., w, Boston, Mass.)

Virginia (E. M. Miller, w, Richmond)

**Flood frequency:**

Transformations for flood data (G. L. Haynes, Jr., w, D)

Alabama, flood frequency synthesis for small streams (J. F. McCain, w, Tuscaloosa)

Alaska (J. M. Childers, w, Anchorage)

Colorado, Denver metropolitan area (G. L. Ducret, Jr., w, Denver)

Georgia (C. M. Bunch, w, Atlanta)

Illinois (D. W. Ellis, w, Champaign)

Iowa (H. H. Schwob, w, Iowa City)

Kansas (T. J. Irza, P. R. Jordan, w, Lawrence)

**Louisiana:**

Flood frequency of small areas (J. L. Simmons, 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 (I. J. Hickenlooper, w, Nashville)

**Utah:**

Magnitude and flood frequency (F. K. Fields, w, Salt Lake City)

Magnitude and frequency (E. Butler, w, Salt Lake City)

Wisconsin, magnitude and frequency (D. H. Conger, w, Madison)

**Flood-inundation mapping:**

Flood-inundation maps (A. R. Green, J. O. Rostvedt, w, W)

Alaska, flood-plain mapping (C. W. Boning, w, Juneau)

Hawaii (R. Lee, 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)

Mississippi, flood-inundation maps of Mississippi gulf coast (K. V. Wilson, w, Jackson)

Missouri, metropolitan St. Louis Sewer District (D. W. Spencer, w, St. Louis)

Nebraska, Milford quadrangle, southeastern Nebraska (F. B. Shaffer, K. J. Braun, w, Lincoln)

New Jersey (H. J. Freiburger, w, Trenton)

New York (S. Hladio, w, Albany)

Oregon, Elk Creek, near Drain (E. A. Oster, w, Portland)

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)

Culebrinas-Aguada area (W. J. Haire)

Guanajibo Valley (W. J. Haire)

Jobos-Guayama area (W. J. Haire)

Lajas Valley (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)

South Dakota, Upper James River (O. J. Larimer, w, Huron)

Tennessee, Nashville-Davidson County metropolitan area (L. G. Conn, w, Nashville)

Texas--Dallas, Bachman Branch, Joes Creek, Turtle Creek, and White Rock Creek (G. R. Dempster, Jr., w, Ft. Worth)

West Virginia, Logan and Martinsburg areas (P. M. Frye, w, Charleston)

Wisconsin, flood inundation study (J. O. Shearman, w, Madison)

**Flood investigations, areal:**

Arkansas River basin, floods of June 1965--Colorado, Kansas, and New Mexico (R. J. Snipes, C. T. Jenkins, D. D. Gonzalez, w, D)

Flood reports (J. O. Rostvedt, w, W)

**Arizona:**

Flood hydrology (B. N. Aldridge, w, Tucson)

Floods from small drainages in Flagstaff (B. N. Aldridge, w, Tucson)

Grand Canyon National Park (M. E. Cooley, w, Tucson)

Infiltration from streamflow in upper Santa Cruz River (B. N. Aldridge, w, Tucson)

Surface flow characteristics and infiltration from streamflow in upper San Pedro basin (B. N. Aldridge, w, Tucson)

Arkansas (M. S. Hines, w, Little Rock)

**California:**

Flood-plain mapping (A. O. Waananen, w, M)

Floods of Jan.-Feb. 1969 (A. O. Waananen, w, M)

Floods of 1966, Kaweah-Kern area (W. W. Dean, w, Sacramento)

Georgia, flood gaging (C. M. Bunch, w, Atlanta)



**Flood investigations, areal--Continued****Hawaii:**

- Flood gaging (R. Lee, w, Honolulu)
- Oahu, hydrology of floods in Moanalua Valley (G. Yamanaga, w, Honolulu)

**Iowa:**

- Flood profiles, statewide (H. H. Schwob, w, Iowa City)
- Flood profiles and flood-plain information, Cedar Rapids (H. H. Schwob, w, Iowa City)
- Flood profiles and flood-plain information, Linn County (H. H. Schwob, w, Iowa City)

**Kansas, statewide (E. R. Hedman, w, Lawrence)****Louisiana, rainfall-runoff and unit hydrographs, northern Louisiana (V. B. Sauer, w, Baton Rouge)****Mississippi, floods of 1966 and 1967 (B. E. Wasson, w, Jackson)****New Jersey, flood warning (E. W. Moshinsky, w, Trenton)****New York, peak discharge of ungaged streams (B. Dunn, w, Albany)****Tennessee, Nashville-Davidson County metropolitan area (L. G. Conn, w, Nashville)****Virginia:****Fairfax County, flood hydrology (F. P. Kapinos, w, Fairfax)****Statewide (E. M. Miller, w, Richmond)****Wyoming, flood-hydrograph investigations in selected drainage areas under 10 square miles (G. S. Craig, Jr., w, Cheyenne)****Fluorspar:****Zoning, epithermal deposits (R. G. Worl, D)****Colorado, Bonanza, and Poncha Springs quadrangles (R. E. Van Alstine, W)****Illinois, southern (D. M. Pinckney, D)****Foreign nations, geologic investigations:****Brazil, mineral resources and geologic training (M. G. White, Rio de Janeiro)****Colombia, minerals exploration and appraisal (E. Irving, Bogotá)****Liberia (W. L. Coonrad, Monrovia)****Pakistan, mineral-resources development (D. L. Rossman, W)****Saudi Arabia, crystalline shield, geologic and minerals reconnaissance (James Norton, Jidda)****Foreign nations, hydrologic investigations. See Water resources, other countries.****Fuels, organic. See Coal; Oil shale; Petroleum and natural gas. Gas, natural. See Petroleum and natural gas.****Geochemical distribution of the elements:****Abundance of heavy metals in sedimentary rocks (H. A. Tourtelot, D)****Botanical exploration and research (H. L. Cannon, D)****Coding and retrieval of geologic data (T. G. Lovering, D)****Data of geochemistry (M. Fleischer, W)****Data of rock analyses (M. Hooker, W)****Data systems (R. V. Mendes, D)****Light stable isotopes (J. R. O'Neil, M)****Metals in volcanoclastic rocks (D. A. Lindsey, D)****Organometallic complexes, geochemistry (P. Zubovic, W)****Sedimentary rocks, chemical composition (H. A. Tourtelot, D)****California, Sierra Nevada batholith, geochemical study (F. Dodge, M)****Kentucky, geochemical census (J. J. Connor, D)****Montana, Boulder batholith, petrochemistry (R. I. Tilling, W)****Geochemical prospecting methods:****Application of silver-gold geochemistry to exploration (H. W. Lakin, D)****Botanical exploration and research (H. L. Cannon, D)****Elements in organic-rich material (F. N. Ward, D)****Gamma-ray spectrometry (J. A. Pitkin, D)****Geochemical exploration studies with volatile elements (J. H. McCarthy, D)****Instrument development (W. W. Vaughn, D)****Jasperoid-relations to ore deposits (T. G. Lovering, D)****Mercury, geochemistry (A. P. Pierce, D)****Mineral-exploration methods (G. B. Gott, D)****Minor elements in detrital minerals (W. C. Overstreet, D)****Mobile spectrographic laboratory (A. P. Marranzino, D)****Ore-deposits controls (A. V. Heyl, Jr., D)****Reconnaissance and geochemical exploration (P. K. Theobald, D)****Sulfides, accessory in igneous rocks (G. J. Neuerberg, D)****Trace analyses (J. B. McHugh, D)****Arizona:****Anomaly characterization (F. C. Canney, D)****Geochemical halos of mineral deposits (L. C. Huff, D)****Idaho, geochemical exploration in Coeur d'Alene (G. B. Gott, D)****Maine, anomaly characterization (F. C. Canney, D)****Nevada-Utah, geochemical halos (R. L. Erickson, D)****New Mexico:****Basin and range part, geochemical reconnaissance (W. R. Griffiths, D)****Geochemical halos of mineral deposits (L. C. Huff, D)****Puerto Rico (R. E. Learned, D)****Geochemistry, experimental:****Diagenesis of feldspars (R. W. Luce, M)****Environment of ore deposition (P. B. Barton, Jr., W)****Experimental mineralogy (R. O. Fournier, M)****Fluid inclusions in minerals (E. W. Roedder, W)****Geologic thermometry (D. B. Stewart, W)****Heavy-metal deposits (J. T. Nash, M)****Heavy metals in igneous rocks (D. Gottfried, W)****Impact metamorphism (E. C. T. Chao, W)****Kinetics of igneous processes (H. R. Shaw, W)****Late-stage magmatic processes (G. T. Faust, W)****Mineral equilibria, low-temperature (E-an Zen, W)****Neutron activation (F. E. Senftle, W)****Organic geochemistry (J. G. Palacas, D)****Organic geochemistry and infrared analysis (P. Zubovic, W)****Organometallic complexes, geochemistry (P. Zubovic, W)****Solution-mineral equilibria (C. L. Christ, M)****Stable isotopes and ore genesis****Geochemistry, water:****Atmospheric precipitation, chemistry (D. W. Fisher, w, W)****Chemical constituents in ground water, spatial distribution (W. Back, w, W)****Corrosion and encrustation mechanisms in water supplies (F. E. Clarke, w, W)****Corrosion and encrustation studies, U.S. Air Force stations (H. L. Heyward, w, Anchorage, Alaska)****Elements, distribution in fluvial and brackish environments (V. C. Kennedy, w, M)****Fluvial geochemistry of silver and gold (T. T. Chao, w, D)****Geochemical controls of water quality (I. Barnes, w, M)****Hydrologic applications of quantitative mineralogy (R. Schoen, w, M)****Hydrosolic metals and related constituents in natural water, chemistry (J. D. Hem, w, M)**

**Geochemistry, water--Continued**

- Hydrous metal oxides, their geochemistry and effect on water quality (E. A. Jenne, w, M)
- Influence of water-seepage characteristics upon the composition of exchangeable pore-water solutes (J. Rubin, w, M)
- Interaction of minerals and water in saline environments (B. F. Jones, w, W)
- Mineralogic controls of the chemistry of ground water (B. B. Hanshaw, w, W)
- Organic geochemistry of San Francisco Bay waters and sediments (D. H. Peterson, w, M)
- Radiochemical surveillance (V. J. Janzer, w, D)
- Trace elements in Missouri waters (G. L. Feder, w, Rolla, Mo.)

*See also* Quality of water.

**Geochemistry and petrology, field studies:**

- Basalt, genesis (T. L. Wright, W)
- Basin and Range granites (D. E. Lee, D)
- Cauldron and ash-flow studies (R. L. Smith, W)
- Crustal abundance in heavy metals (R. V. Mendes, D)
- East and central San Juan volcanic field, Colorado (P. W. Lipman, D)
- Epithermal deposits (R. G. Worl, D)
- Geochemical halos, Utah-Nevada (R. L. Erickson, D)
- Geochemical studies in Southeastern States (H. Bell III, Beltsville, Md.)
- Geochemical survey of the Rocky Mountain region (J. D. Vine, D)
- Geochemistry of diagenesis (K. J. Murata, M)
- Geochemistry of heavy metals in the weathering and erosion of granite (Z. S. Altschuler, W)
- Geochemistry of sediments, San Francisco Bay, Calif. (D. S. McCulloch, M)
- Humates, geology and geochemistry, Florida, New Mexico, and Wyoming (V. E. Swanson, D)
- Inclusions in basaltic rocks (E. D. Jackson, M)
- Layered intrusives (N. J. Page, M)
- Marine volcanic rocks (C. G. Engel, La Jolla, Calif.)
- Mercury, geochemistry and occurrence (A. P. Pierce, D)
- Meteorites, petrology (P. R. Brett, W)
- Niobium and tantalum, distribution in igneous rocks (D. Gottfried, W)
- Oceanic rocks and evolution of earth's crust (A. E. J. Engel, La Jolla, Calif.)
- Oil shale, organic geochemistry (R. E. Miller, D)
- Ore lead, geochemistry and origin (R. S. Cannon, D)
- Pierre Shale, chemical and physical properties, Montana, North Dakota, Nebraska, South Dakota, and Wyoming (H. A. Tourtelot, D)
- Radiogenic heat sources in the crust and mantle (R. I. Tilling, W)
- Rare-earth elements, resources and geochemistry (J. W. Adams, D)
- Regional metamorphic studies (H. L. James, W)
- Residual minor elements in igneous rocks and veins (G. Phair, W)
- Services (P. H. Held, M; H. J. Miller, W)
- Solution transport of heavy metals (G. K. Czamanske, M)
- Thermal waters, origin and characteristics (D. E. White, M)
- Titanium, geochemistry and occurrence (N. Herz, W)
- Ultramafic rocks, petrology of alpine types (R. G. Coleman, M)

**California:**

- Coast Range ultramafic rocks (R. S. Loney, M)

**Geochemistry and petrology, field studies--Continued****California--Continued**

- Kings Canyon National Park (J. G. Moore, M)
- Ritter Range metavolcanic rocks (R. S. Fiske, W)
- Sierra Nevada metamorphism (B. A. Morgan III, W)
- Idaho, Wood River district (W. E. Hall, M)

**Montana:**

- Bearpaw Mountains, petrology (B. C. Hearn, Jr., W)
- Boulder batholith, petrochemistry (R. I. Tilling, W)
- Stillwater complex, petrology and chromite resources (E. D. Jackson, M)

- Wolf Creek area, petrology (R. G. Schmidt, W)

- New Mexico, Valles Mountains (R. L. Smith, W)

- Utah, Mule Ear (D. E. Stuart-Alexander, M)

**Wyoming:**

- Absaroka volcanic rocks, eastern Yellowstone National Park (H. W. Smedes, D)
- Rhyolitic rocks of Yellowstone National Park (R. L. Christiansen, D)
- Yellowstone thermal area, geology (L. J. P. Muffler, M)

**Geochronology:**

- Carbon-14 method (M. Rubin, W)
- Geochronology, Denver (Z. E. Peterman, J. Obradovich, D)
- Igneous rocks and deformational periods (R. W. Kistler, M)
- Lead-uranium method (T. W. Stern, W)
- Post-Pleistocene alluviation and erosion in the lower San Juan drainage (D. O'Bryan, M. E. Cooley, T. C. Winter, w, W)
- Potassium-argon and rubidium-strontium methods (M. A. Lanphere, W)
- Radioactive-disequilibrium studies (J. N. Rosholt, D)
- See also* Isotope and nuclear studies.

**Geologic mapping:**

- Geologic map of the United States (P. B. King, M)
- Map scale smaller than 1 inch to 1 mile:
  - Colorado Plateau, geologic maps (2-degree sheets) (D. G. Wyant, D)
- Sino-Soviet terrain atlas (J. Rachlin, W)
- Alaska:
  - Brooks Range, southern part (W. P. Brosge, M)
  - Charley River quadrangle (E. E. Brabb, M)
  - Delong Mountains quadrangle (I. L. Tailleir, M)
  - Hughes-Shungnak area (W. W. Patton, Jr., M)
  - Iliamna quadrangle (R. L. Detterman, M)
  - Lower Yukon-Norton Sound region (J. M. Hoare, M)
  - Northern part, petroleum investigations (G. Gryc, M)
  - Point Hope quadrangle (I. L. Tailleir, M)
  - St. Lawrence Island (W. W. Patton, Jr., M)
  - Seward Peninsula (C. L. Sainsbury, D)
  - Southeast Alaska (D. A. Brew, M)
  - Tanacross-Eagle quadrangle (H. L. Foster, M)
- Arkansas, geologic map (B. R. Haley, Little Rock)

**Colorado:**

- Oil-shale investigations (D. C. Duncan, W)
- Durango 2-degree quadrangle (T. A. Steven, D)
- Grand Junction 2-degree quadrangle (W. B. Cashion, D)
- Lamar 2-degree quadrangle (J. A. Sharps, D)
- Limon 2-degree quadrangle (J. A. Sharps, D)
- Montrose 1:250,000 quadrangle (W. J. Hail, Jr., D)
- Pueblo 2-degree quadrangle (G. R. Scott, D)

**Idaho:**

- Preston 2-degree quadrangle (S. S. Oriel, D)
- Snake River plain, central part, volcanic petrology (H. E. Malde, D)

# Geologic mapping--Continued

## Map scale smaller than 1 inch to 1 mile--Continued

### Idaho--Continued

Spokane-Wallace region (A. B. Griggs, M)

Montana, Spokane-Wallace region (A. B. Griggs, M)

### Nevada:

Elko County (R. A. Hope, M)

Geologic map of State (J. H. Stewart, M)

Lander County (J. H. Stewart, M)

Lincoln County, Tertiary rocks (F. N. Houser, D)

Nye County, northern part (F. J. Kleinhampl, M)

Nevada Test Site, special studies (L. M. Gard, E. B. Ekren, D)

Pershing County (D. B. Tatlock, M)

White Pine County (R. K. Hose, M)

New Mexico, Black Range (G. E. Erickson, W)

### North Carolina:

Knoxville 2-degree quadrangle (J. B. Hadley, Beltsville, Md.)

Winston-Salem 2-degree quadrangle (D. W. Rankin, G. H. Espenshade, W)

Oregon, geologic map (G. W. Walker, M)

South Carolina, Knoxville 2-degree quadrangle (J. B. Hadley, W)

South Dakota, Black Hills (J. A. Redden, D)

### Tennessee:

Knoxville 2-degree quadrangle (J. B. Hadley, W)

Winston-Salem 2-degree quadrangle (D. W. Rankin, G. H. Espenshade, W)

Utah, Grand Junction 2-degree quadrangle (W. B. Cashion, D)

Virginia, Winston-Salem 2-degree quadrangle (D. W. Rankin, G. H. Espenshade, W)

Washington, Spokane-Wallace region (A. B. Griggs, M)

### Wyoming:

Geologic map of State (W. R. Keefer, D)

Preston 2-degree quadrangle (S. S. Oriel, D)

Yellowstone National Park, compilation and nontechnical report (W. R. Keefer, D)

## Map scale 1 inch to 1 mile, and larger:

### Alaska:

Annette Island (H. C. Berg, M)

Bering River coal field (A. A. Wanek, c, Anchorage)

Cape Beaufort-Corwin Bluffs coal field (A. A. Wanek, c, Anchorage)

Fairbanks district (R. M. Chapman, M)

Kukpowruk River coal field (A. A. Wanek, c, Anchorage)

Livengood quadrangle (R. M. Chapman, M)

Nenana coal investigations (C. Wahrhaftig, M)

Southern Wrangell Mountains (E. M. MacKevett, Jr., M)

Yakutat (G. Plafker, M)

Antarctica, Pensacola Mountains (D. L. Schmidt, D)

### Arizona:

Bradshaw Mountains (C. A. Anderson, M)

Cochise County, southern part (P. T. Hayes, D)

Cummings Mesa quadrangle (F. Peterson, c, D)

Empire Mountains (T. L. Finnell, D)

Garnet Mountain quadrangle (P. M. Blacet, M)

Gunsight Butte SE and SW quadrangles (F. Peterson, c, D)

Lochiel and Nogales quadrangles (F. S. Simons, D)

Mt. Wrightson quadrangle (H. Drewes, D)

# Geologic mapping--Continued

## Map scale 1 inch to 1 mile, and larger--Continued

### Arizona--Continued

Nipple Butte 15-minute quadrangle (H. A. Waldrop, c, D)

Ray district, porphyry copper (H. R. Cornwall, M)

Sahuarita quadrangle (H. D. Drewes, D)

### California:

Big Maria Mountains (W. B. Hamilton, D)

Bucks Lake quadrangle (A. Hietanen-Makela, M)

Coast Range, ultramafic rocks (E. H. Bailey, M)

Furnace Creek area (J. F. McAllister, M)

Hernandez Valley quadrangle (W. C. Gere, c, Los Angeles, Calif.)

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 Triunfo 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 metropolitan area (R. M. Lindvall, D)

Front Range, northeastern part, Fort Collins area (W. A. Braddock, D)

Jefferson quadrangle (F. Barker, D)

Kremmling quadrangle (G. A. Izett, c, D)

Mellen Hill quadrangle (H. L. Cullins, c, D)

Montezuma quadrangle (F. Barker, D)

Nederland quadrangle (D. J. Gable, D)

Northern Park Range (G. L. Snyder, D)

Peoria quadrangle (P. E. Soister, c, 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.)

**Geologic mapping--Continued**

Map scale 1 inch to 1 mile, and larger--Continued

**Colorado--Continued**

Woody Creek quadrangle (V. L. Freeman, D)

**Connecticut:**

Connecticut cooperative mapping program (L. R. Page, Boston, Mass.)

Taconic sequence (E-an Zen, W)

District of Columbia, Washington metropolitan area (H. W. Coulter, C. F. Withington, W)

Florida, Attapulugus-Thomasville area, fuller's earth deposits (S. H. Patterson, Beltsville, Md.)

Georgia, Attapulugus-Thomasville area, fuller's earth deposits (S. H. Patterson, Beltsville, Md.)

**Idaho:**

Bayhorse area (S. W. Hobbs, D)

Boulder Mountains (C. M. Tschanz, D)

Elmira quadrangle (J. E. Harrison, D)

Goat Mountain quadrangle (M. H. Staatz, D)

Hawley Mountain quadrangle (W. J. Mapel, D)

Henry's 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)

Palisades Peak quadrangle (D. A. Jobin, c, D)

Palisades Reservoir quadrangle (H. F. Albee, c, Salt Lake City, Utah)

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)

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)

**Geologic mapping--Continued**

Map scale 1 inch to 1 mile, and larger--Continued

**Michigan--Continued**

Western Negaunee quadrangle (L. D. Clark, M)

Mississippi, Homochitto National Forest (E. L. Johnson, c, Tulsa, Okla.)

**Montana:**

Barker quadrangle (I. J. Witkind, D)

Bearpaw Mountains, petrology (B. C. Hearn, Jr.)

Black Butte 7½-minute quadrangle (L. M. McGrew, Laramie, Wyo.)

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)

Henry's 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)

Moorhead coal field (N. W. Bass, c, D)

Neihart 1 quadrangle (W. R. Keefer, D)

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)

Coaldale area (L. H. Godwin, c, M)

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)

Midas-Jarbridge 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 4 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)

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)

Samson Lake quadrangle (J. E. Fassett, c, Farmington)

San Juan basin, east side (E. R. Landis, D)

Twin Butte quadrangle (J. E. Fassett, c, Farmington)

Valles Mountains, petrology (R. L. Smith, W)

**Geologic mapping--Continued**

Map scale 1 inch to 1 mile, and larger--Continued

New Mexico--Continued

Wingate-Thoreau area (C. T. Pierson, D)

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)

Anthraccite 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:

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:

Bingham Canyon district (E. W. Tooker, M)

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)

Conger Mountains (L. F. Hintze, Provo, Utah)

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)

Gilbert Peak 1 NE quadrangle (E. M. Schell, c, Billings, Mont.)

Griffin Point quadrangle (W. E. Bowers, c, D)

Gunsight Butte 15-minute quadrangle (F. Peterson, c, D)

**Geologic mapping--Continued**

Map scale 1 inch to 1 mile, and larger--Continued

Utah--Continued

Henrieville quadrangle (W. E. Bowers, c, D)

Jessen Butte quadrangle (E. M. Schell, c, Billings, Mont.)

Morgan quadrangle (T. E. Mullens, c, D)

Nipple Butte 15-minute quadrangle (H. A. Waldrop, 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)

Phil Pico Mountain quadrangle (J. R. Dyni, c, D)

Pine Lake quadrangle (W. E. Bowers, c, D)

Raft River area (R. R. Compton, M)

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)

Upper Valley quadrangle (W. E. Bowers, c, D)

Vernal phosphate area (E. M. Schell, c, Billings, Mont.)

Wide Hollow Reservoir quadrangle (E. V. Stephens, c, Los Angeles, Calif.)

Willard Peak area (M. D. Crittenden, Jr., M)

Virginia:

Appalachian folded belt, southern part (L. D. Harris, Knoxville, Tenn.)

Delmarva Peninsula (J. P. Owens, Beltsville, Md.)

Fairfax quadrangle (P. M. Hanshaw, W)

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)

Loomis quadrangle (C. D. Rinehart, M)

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)

Wyoming:

Albany and Keystone quadrangles (M. E. McCallum, Fort Collins, Colo.)

Alkali Butte quadrangle (M. W. Reynolds, D)

Badwater Creek (R. E. Thaden, D)

Bailey Lake quadrangle (M. L. Schroeder, c, D)

Beartooth Butte quadrangle (W. G. Pierce, M)

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)

Clark Fork quadrangle (W. G. Pierce, M)

Clause Peak quadrangle (M. L. Schroeder, c, D)

Cokeville and adjacent quadrangles (W. W. Rubey, Los Angeles, Calif.)

Deep Lake quadrangle (W. G. Pierce, M)

**Geologic mapping--Continued****Map scale 1 inch to 1 mile, and larger--Continued****Wyoming--Continued**

- Deer Creek quadrangle (D. A. Jobin, c, D)
- Devils Tooth quadrangle (W. G. Pierce, M)
- Ferris quadrangle (R. L. Rioux, c, W)
- Ferry Peak quadrangle (D. A. Jobin, c, D)
- Gas Hills area (F. C. Armstrong, Spokane, Wash.)
- Grand Teton National Park (J. D. Love, Laramie)
- 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)
- Jessen Butte quadrangle (E. M. Schell, c, Billings, Mont.)
- LaBarge 1 SW and 2 SE quadrangles (R. L. Rioux, c, W)
- Lander area phosphate reserve (W. L. Rohrer, 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)
- Pine Creek quadrangle (D. A. Jobin, c, D)
- Poison Spider quadrangle (W. H. Laraway, c, Casper)
- Reid Canyon quadrangle (W. H. Laraway, c, Casper)
- 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)
- Wapiti quadrangle (W. G. Pierce, M)
- Wind River Basin, regional stratigraphy (W. R. Keefer, D)
- Yellowstone National Park, south-central part, pre-Tertiary rocks (W. R. Keefer, D)

**Puerto Rico (R. P. Briggs, San Juan)****Geomorphology:**

- Geomorphology and hydrology, basic research (C. W. Carlston, w, W)
- Mudflow studies (D. R. Crandell, D)
- Ohio River Quaternary (M. P. Weiss, DeKalb, Ill.)
- Ohio River valley, geologic development (L. L. Ray, W)
- Relation of drainage networks and basin development to rock type and climate (R. F. Hadley, w, D)
- Sediment effects on fluvial morphology (S. A. Schumm, w, Fort Collins, Colo.)

**California:**

- Channel morphology, San Francisquito Creek (J. R. Crippen, w, M)
- Sierra Nevada, geomorphic studies (R. J. Janda, w, M)
- Indiana, channel-meander studies (J. F. Daniel, w, Indianapolis)
- New Mexico, Santa Fe, particle movement and channel scour and fill of an ephemeral arroyo (L. B. Leopold, w, W)

**Wyoming:**

- Wind River Mountains, Quaternary geology (G. M. Richmond, D)

**Geomorphology--Continued****Wyoming--Continued**

- Yellowstone National Park, glacial and postglacial geology (G. M. Richmond, D)

*See also* Sedimentation; Geochronology.

**Geophysics, regional:**

- Aeroradioactivity surveys, California, San Andreas fault (W. H. Jackson, M)
- Borehole geophysics (C. J. Zablocki, D)
- Crust and upper mantle:
  - Aeromagnetic investigation for crustal studies (I. Zietz, W)
  - Analysis of traveltimes data (J. C. Roller, M)
  - Crustal strain studies (R. O. Burford, M)
  - Geophysical studies (I. Zietz, W)
  - Geophysical studies, Nevada Test Site, Nevada (G. D. Bath, D)
  - Seismologic studies (J. P. Eaton, M)
  - Fault-zone geophysical studies (W. H. Jackson, M)

**Remote sensing:**

- Environmental effects (K. Watson, D)
- Geochemical anomalies (F. C. Canney, D)
- Geologic applications (G. W. Greene, D)
- Infrared studies, New England (J. D. Friedman, W)
- Infrared spectrometry and imagery (R. M. Moxham, W)
- Radar interpretation (A. N. Kover, W)
- Remote sensors—automatic data processing (K. Watson, D)
- Rock magnetism, northern Rocky Mountains (W. F. Hanna, M)
- See also* Remote sensing, hydrologic applications.
- Remote sensing and advanced techniques, geologic applications (G. D. Robinson, D)
- Ultramafic rocks, geophysical studies, intrusions (G. A. Thompson, M)
- Upper mantle gravity studies, west of the Mississippi (D. R. Mabey, D)
- Antarctica, Pensacola Mountains, geophysical studies (J. C. Behrendt, Monrovia, Liberia)
- Florida Continental Shelf, gravity studies (H. Krivoy, Corpus Christi, Tex.)

**New England:**

- Geophysical studies (M. F. Kane, W)
- Magnetic properties of rocks (A. Griscom, M)
- Pacific Northwest, geophysical studies (M. D. Kleinkopf, D)
- Pacific Southwest, geophysical studies (D. R. Mabey, D)
- Pacific States, geophysical studies (A. Griscom, M)
- United States, aeromagnetic surveys (J. L. Meuschke, D)
- Yellowstone National Park, geophysical study (H. R. Blank, Eugene, Oreg.)

**Alaska:**

- Applied geophysics, Amchitka Island (G. D. Bath, D)
- Regional gravity surveys (D. F. Barnes, M)
- Arizona, Safford Valley, geophysical studies (G. P. Eaton, D)

**California:**

- Los Angeles basin, gravity study (T. H. McCulloh, M)
- San Andreas fault, ground studies (W. F. Hanna, M)
- Sierra Nevada, geophysical studies (H. W. Oliver, M)
- Colorado, Middle Park-North Park basins, geophysical studies (J. C. Behrendt, Monrovia, Liberia)
- District of Columbia, eastern Piedmont, geophysical studies (S. K. Neuschel, W)
- Island Falls quadrangle, electromagnetic mapping (F. C. Frischknecht, W)
- Maryland, Piedmont (J. W. Allingham, W)

**Geophysics, regional--Continued****Massachusetts:**

- Application of geology and seismology to public-works planning (L. R. Page, Boston)
- Cooperative survey (J. L. Meuschke, D)
- Geophysical studies (M. F. Kane, W)

**Minnesota:**

- Keweenaw rocks, magnetic studies (K. G. Books, W)
- Southern part, aeromagnetic survey (E. R. King, W)

**Nevada:**

- Applied geophysics, Nevada Test Site (G. D. Bath, D)
- Nevada Test Site (R. D. Carroll, D)

**New Hampshire, aeromagnetic survey (R. W. Bromery, Amherst, Mass.)****North Carolina, Piedmont (J. W. Allingham, W)****Pennsylvania, magnetic properties of rocks (A. Griscom, M)****Texas, coastal plain, geophysical and geological studies (D. H. Eargle, Austin)****Virginia, eastern Piedmont, geophysical studies (S. K. Neuschel, W)****Geophysics, theoretical and experimental:**

- Crustal studies (ARPA) (I. Zietz, W)
- Earth structure studies (J. H. Healy, M)
- Earthquakes, local seismic studies (J. P. Eaton, M)
- Elastic and inelastic properties of earth materials (L. Peselnick, M)
- Electrical properties of rocks (R. D. Carroll, D)
- Geophysical data, interpretation using electronic computers (R. G. Henderson, W)
- Geophysical program and systems development (G. E. Andreasen, W)
- Geothermal studies (A. H. Lachenbruch, M)
- Ground motion studies (J. H. Healy, M)
- Induced polarization (L. A. Anderson, D. B. Hoover, D)
- Infrared and ultraviolet radiation studies (R. M. Moxham, W)
- Magnetic and luminescent properties (F. E. Senftle, W)
- Magnetic model studies (G. E. Andreason, W)
- Magnetic properties laboratory (M. E. Beck, Jr., Bellingham, Wash.)
- Project Sterling (J. H. Healy, M)
- Remanent magnetization of rocks (R. R. Doell, M)
- Resistivity interpretation (A. A. R. Zohdy, D)
- Rock behavior at high temperature and pressure (E. C. Robertson, W)
- Stress studies (C. B. Raleigh, M)
- Thermodynamic properties of rocks (R. A. Robie, W)
- Ultramafic intrusions, geophysical studies (G. A. Thompson, M)

**Glacial geology, Antarctica, Pensacola Mountains (D. L. Schmidt, D)****Glaciology:**

- Glaciological research, International Hydrological Decade (M. F. Meier, w, Tacoma, Wash.)
- Ice Dynamics (W. J. Campbell, w, Tacoma, Wash.)
- Water, ice, and energy balance of mountain glaciers, and ice physics (M. F. Meier, w, Tacoma, Wash.)
- Alaska, Gulkana and Wolverine glaciers (L. R. Mayo, w, Fairbanks)

**Gold:**

- Composition related to exploration (J. C. Antweiler, D)
- Microprobe analyses (G. A. Desborough, D)
- Placer deposits:
  - Alaska Range, central and eastern (O. J. Ferrians, Jr., M)

**Gold--Continued****Placer deposits--Continued**

- New Mexico (K. Segerstrom, D)
- Western United States (M. G. Johnson, M)

**Alaska:**

- Gulf of Alaska, nearshore (E. H. Lathram, M)
- Seward Peninsula, nearshore (D. M. Hopkins, M)
- Appalachian region, southern part (F. G. Lesure, W)
- Arizona, Gold Basin-Lost Basin district (P. M. Blacet, M)

**California:**

- Klamath Mountains (P. E. Hotz, M)
- Mother Lode (S. C. Creasey, M)
- Sierra Nevada, Tertiary gravels (W. E. Yeend, M)
- Great Lakes region (D. A. Seeland, D)
- Idaho and Utah, conglomerates (T. E. Mullens, D)

**Montana:**

- Confederate Gulch (W. B. Myers, D)
- Cooke City quadrangle (J. E. Elliott, D)
- Southwestern part, ore deposits (K. L. Wier, D)

**Nevada:**

- Aurora and Bodie districts, Nevada-California (F. J. Kleinhampl, M)
- Carlin mine (A. S. Radtke, M)
- Comstock district (D. H. Whitebread, M)
- Cortez window and vicinity (J. D. Wells, D)
- Dun Glen quadrangle (D. H. Whitebread, M)
- Goldfield district (R. P. Ashley, M)
- Midas-Jarbridge area (R. R. Coats, M)
- Shoshone Range (C. T. Wrucke, M)
- North Carolina, Gold Hill area (A. A. Stromquist, D)
- Oregon-Washington, nearshore area (P. D. Snavelly, Jr., M)
- South Dakota, northern Black Hills (R. W. Bayley, M)
- Wyoming, northwestern part, conglomerates (J. C. Antweiler, D)

**See also Heavy Metals.****Ground water-surface water relations:**

- Flow losses in ephemeral stream channels (R. F. Hadley, w, D)
- Florida, Lake Okeechobee, levee underseepage (F. W. Meyer, w, Miami)
- Hawaii, Kailua, water-table mapping (C. J. Huxel, w, Honolulu)
- Kansas (W. M. Kastner, w, Lawrence)
- Kentucky, ground water in alluvium of Ohio River Valley, development and management (H. F. Grubb, w, Louisville)
- New Jersey, hydrologic analysis of the Pine Barrens (E. C. Rhodehamel, w, Trenton)
- New Mexico:
  - Pecos River--miscellaneous (G. E. Welder, w, Roswell)
  - Pojoaque drainage basin (F. C. Koopman, w, Albuquerque)
- Texas, relation of impounded floodwater from Hurricane Buelah to ground water in Kleberg, Kenedy, and Willacy Counties (E. T. Baker, Jr., w, Austin)

**Wisconsin:**

- Augmenting low flows of streams with ground water (R. P. Novitzki, w, Madison)
- Hydrologic effects of dredging small spring ponds (W. J. Rose, w, Madison)
- Wetlands, hydrology (L. J. Hamilton, w, Madison)

**Heavy Metals:**

- Abundance in sedimentary rocks (H. A. Tourtelot, D)
- Crustal abundance of heavy metals (R. V. Mendes, D)



**Heavy Metals--Continued**

- Fluvial transport of heavy metals (C. F. Nordin, Jr., w, Fort Collins, Colo.)
- Heavy metals in igneous rocks (D. Gottfried, W)
- Mineral paragenesis (J. T. Nash, M)
- Mineralogy (F. A. Hildebrand, D)
- Reconnaissance and geochemical exploration (P. K. Theobald, D)
- Regional variation in heavy-metals content of Colorado Plateau stratified rocks (R. A. Cadigan, D)
- Solution transport (G. K. Czamanske, M)
- Appalachian region:
  - Northeastern, heavy minerals (J. P. D'Agostino, Beltsville, Md.)
  - South-central (A. A. Stromquist, D)
  - Southeastern, sediments (J. P. Minard, W)
- Rocky Mountain region, fossil beach placers (R. S. Houston, Laramie, Wyo.)
- Southeastern States, geochemical studies (H. Bell III, Beltsville, Md.)
- Alaska:
  - Eastern Brooks Range (W. P. Brosge', M)
  - Gulf of Alaska, nearshore placers (Erk Reimnitz, M)
  - Hogatz trend, Alaska (T. P. Miller, M)
  - Seward Peninsula (C. L. Sainsbury, D)
  - Southeastern part (D. A. Brew, M)
  - Southern Alaska Range (B. L. Reed, M)
  - Southwestern part (J. M. Hoare, M)
  - Yukon-Tanana Upland (H. L. Foster, M)
- Colorado:
  - Northwestern part, exploration (K. Segerstrom, D)
  - San Juan Mountains, northwestern (R. P. Fischer, D)
- Idaho, conglomerates (T. E. Mullens, D)
- Maine, West Pembroke (R. H. Moench, D)
- Nevada:
  - Aurora and Bodie districts, Nevada-California (F. J. Kleinhampl, M)
  - Basin and Range, heavy-metals studies (D. R. Shawe, D)
  - Copper Canyon deposit (T. G. Theodore, M)
  - Elko County, central part (K. B. Ketner, D)
  - North-central part (R. J. Roberts, M)
- North Carolina, southwestern part, reconnaissance (J. W. Whitlow, Beltsville, Md.)
- Utah:
  - Conglomerates (T. E. Mullens, D)
  - Geologic controls (A. V. Heyl, D)
- 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)
  - Dielectric behavior of water-bearing sediments (W. O. Smith, C. E. Mongan, w, W)
  - Mechanics of aquifer systems (J. F. Poland, w, Sacramento, Calif.)
  - Mechanics of ground-water flow (H. H. Cooper, Jr., 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)

**Hydraulics, ground water--Continued**

- Theory of multiphase flow—applications (E. P. Weeks, w, D)
- Transient flow in sediments (W. O. Smith, C. E. Mongan, w, W)
- Transport processes in fluid flows (A. Ogata, w, Honolulu, Hawaii)
- Unsaturated flow of water in sediments (W. O. Smith, w, W)
- Velocities of ground water and radionuclides at the Amargosa tracer site, Nevada (D. B. Grove, E. H. Cordes, w, D)
- California:
  - Aquifer-test reevaluation (E. J. McClelland, w, Sacramento)
  - Subsidence, San Bernardino Valley (R. E. Miller, w, Garden Grove)
- 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)
- Hydraulics, surface flow:**
  - Channel characteristics, California:
    - Channel capacity, Chowchilla River (G. L. Bertoldi, w, Sacramento)
    - Channel capacity, San Joaquin River (K. W. Lee, w, Sacramento)
    - Feather River channel capacity (J. Blodgett, w, Sacramento)
    - Fresno 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 (C. B. Nuckolls, w, Jackson, Miss.)
  - Scour research at bridge piers, Alaska (L. S. Leveen, w, Anchorage)
  - Verification of hydraulic techniques (W. J. Randolph, w, Nashville, Tenn.)
- Flow characteristics:**
  - Alluvial channel flow (C. F. Nordin, Jr., w, Fort Collins, Colo.)
  - Dispersion by turbulent flow in open channels (N. Yotsukura, w, W)
  - Dispersion processes in estuaries and rivers (H. B. Fischer, w, University of California, Berkeley)
  - Effect of temperature on winter runoff (W. D. Simons, w, M)
  - Floods from small drainages, California (A. O. Waananen, w, M)
  - Hydraulic geometry of streams, Kansas (C. V. Burns, Lawrence, Kans.)

**Hydraulics, surface flow--Continued****Flow characteristics--Continued**

- Hydraulics of Port Royal Sound estuarine system (T. R. Cummings, 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)
- Vertical-velocity characteristics, Columbia River gaging stations, Washington and Oregon (J. Savini, w, Tacoma, Wash.; G. L. Bodhaine, w, W)

**Laboratory studies:**

- Grain-size distribution and bedload transport (G. Williams, w, W)

**Time-of-travel studies:**

- Time-of-travel measurements in major river systems (Ellis Donsky, w, Trenton, N.J.)
- California, San Joaquin River, residence time (G. O. Balding, w, Sacramento)
- Indiana (R. E. Hoggatt, w, Indianapolis)
- Maryland (K. R. Taylor, w, Towson)
- Mississippi, Tombigbee River (F. H. Thomson, w, Jackson)
- New York (H. L. Shindel, w, Albany)

*See also* Hydrologic instrumentation.

**Hydrologic-data collection and processing:**

- Channel processes (W. W. Emmett, w, W)
- Data storage, retrieval, and application by digital-computer techniques (C. O. Morgan, w, Lawrence, Kans.)

**Drainage-area determinations:**

- Indiana (R. E. Hoggatt, w, Indianapolis)
- Kentucky (H. C. Beaver, 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)**

- Rhode River project, Anne Arundel County, Md. (R. L. Cory, J. W. Nauman, R. L. Nace, A. Sinnott, w, W)

**Sediment loads in streams—methods used in measurement and analysis (J. V. Skinner, w, Minneapolis, Minn.)**

- Statistical inferences (E. J. Gilroy, w, W)
- Water budget of North America (A. Wilson, w, W)
- Colorado, statistical design of data collection network (R. R. Luckey, w, D)
- Kentucky, inventory of public and industrial water use (D. S. Mull, w, Louisville)
- Maryland, inventory and automation of well and pumping records (W. E. Webb, w, Towson)
- New York, Long Island, storage and retrieval of hydrologic data (D. E. Vaupel, w, Mineola)

**Hydrologic-data collection and processing--Continued**

- Oregon, Portland harbor, scour at bridge piers (R. W. Childreth, w, Portland)

*See also* Hydrologic instrumentation.

**Hydrologic instrumentation:**

- Acoustic-velocity meter, Chipps Island, Calif. (W. Smith, w, M)
- Borehole geophysics as applied to geohydrology (W. S. Keys, w, D)
- Development of techniques for measurement of moisture-energy relationships in soils and vegetation (I. S. McQueen, w, D)
- Electronic-equipment development—water (J. E. Eddy, w, W)
- Energy-budget evaporation studies, instruments (C. R. Daum, w, D)
- Instrumentation research—water (H. O. Wires, w, Columbus, Ohio)
- Laboratory research, instruments, water (G. F. Smoot, w, W)

*See also* Hydrologic-data collection and processing.

**Hydrology, ground-water:**

- Geohydrologic environmental study (J. N. Payne, w, Baton Rouge, La.)
- Geologic structure and fresh ground water in the Gulf Coastal Plain (P. H. Jones, w, St. Louis, Mo.)
- Hydrogeology of carbonate rocks (V. T. Stringfield, w, W)
- Hydrology of the crystalline-rock system in Southeastern States (H. E. LeGrand, w, Raleigh, N.C.)
- Delaware, quantitative appraisal of Pleistocene aquifers (R. H. Johnston, w, Dover)
- Iowa, geohydrology of alluvial aquifer in vicinity of Red Rock Dam, Des Moines River (W. L. Steinhilber, w, Iowa City)

**Maryland:**

- Sanitary landfills in the geohydrologic environment (E. G. Otton, w, Towson)
- Underground disposal of liquid wastes in brackish-water formations (E. G. Otton, w, Towson)

**New York:**

- Long Island, hydrologic effects of recharge basins (G. E. Seaburn, w, Mineola)
- Suffolk County, hydrologic conditions (H. M. Jensen, w, Mineola)
- Western Long Island, analog model (O. L. Franke, w, Mineola)

**North Dakota, hydrology of prairie potholes (W. S. Eisenlohr, Jr., w, D)****Oregon, basalt aquifers, Hermiston-Ordinance area (J. H. Robison, w, Portland)****Tennessee:**

- Limestone aquifers, upper Stones River basin (G. K. Moore, w, Nashville)
- Upper Duck River basin (C. R. Burchett, w, Nashville)

**Hydrology, surface-water:**

- Arkansas, time-of-travel studies of Arkansas streams (T. E. Lamb, w, Little Rock)

**California:**

- Changes in regimen, Santa Ana River (M. B. Scott, w, Garden Grove)
- History of streambed changes, southern California (R. Williams, w, Garden Grove)
- Hydrology of Prado Reservoir (M. W. Busby, w, Garden Grove)
- Infiltrimeter studies (J. Limerinos, w, Menlo Park)

**Hydrology, surface-water--Continued****California--Continued**

Mojave River drainage hydrology (G. Hirashima, w, Garden Grove)

Estuaries, South Carolina, reconnaissance studies (T. R. Cummings, w, Columbia)

**Lakes and reservoirs:****Arkansas:**

Horseshoe Lake (A. G. Lamonds, w, Little Rock)

Streamflow, rainfall, and trap efficiency studies (S. R. Kennedy, w, Ft. Smith)

Florida, statewide, lake studies (G. H. Hughes, w, Tallahassee)

Missouri, small lakes (E. E. Gann, w, Rolla)

Montana, Hungry Horse Reservoir (M. I. Rorabaugh, w, St. Louis, Mo.; W. D. Simons, w, M)

Nevada, bathymetric survey of Lahontan Reservoir (E. E. Harris, w, Carson City)

North Dakota, hydrology of prairie potholes (W. S. Eisenlohr, Jr., w, D)

Oregon, Abert Lake and other closed-basin lakes in Oregon, hydrology and geochemistry (A. S. Van Denburgh, w, Carson City, Nev.)

Washington, lakes of Washington (M. R. Collings, w, Tacoma)

*See also* Evaporation; Limnology.

Major hydrologic limitations on interregional transfers of water (A. M. Piper, w, M)

**Streams:**

Alabama, Wragg Swamp Canal investigation, second phase (J. F. McCain, w, Tuscaloosa)

Alaska, statewide stream discharge and (or) stage (H. Hulsing, w, Anchorage)

California, Eastern San Gabriel hydrology (G. Hirashima, w, Garden Grove)

Massachusetts, Merrimack River estuary and Millers River, infrared imagery study (J. E. Cotton, w, Boston)

Mississippi, Pearl River boatway studies (C. P. Humphreys, Jr., w, Jackson)

Missouri, over-year storage requirements for Missouri streams (J. Skelton, w, Rolla)

Nevada, small drainage areas, floods (R. D. Lamke, w, Carson City)

New Hampshire, small streams (C. E. Hale, w, Boston, Mass.)

**Oregon:**

Alsea River basin, effects of logging on streamflow, sedimentation, and temperature (R. C. Williams, w, Cheyenne, Wyo.; D. D. Harris, w, Portland)

Tualatin River basin (C. H. Swift III, w, Portland)

Pennsylvania, Philadelphia area (R. A. Miller, w, Harrisburg)

**Tennessee:**

Water resources of Center Hill Lake region (G. K. Moore, w, Nashville)

Water resources of upper Stones River basin (C. R. Burchett, w, Nashville)

**Wisconsin:**

Effects of small impoundments on the interrelationships between aquatic biota and chemical quality of Nederlo Creek (P. A. Kammerer, w, Madison)

Hydrologic effects of a small reservoir, Nederlo Creek basin (P. A. Kammerer, w, Madison)

**Hydrology, surface-water--Continued**

*See also* Evapotranspiration; Flood investigations, areal; Marine hydrology; Mining hydrology; Model studies, hydrologic; Plant ecology; Urbanization, hydrologic effects.

**Lead, zinc, and silver:**

Lead isotopes and ore deposits (R. E. Zartman, D)

Ore lead, geochemistry and origin (R. S. Cannon, D)

Zoning, epithermal deposits (R. G. Worl, D)

Arizona, Lochial and Nogales quadrangles (F. S. Simons, D)

**Colorado:**

Rico district (E. T. McKnight, W)

San Juan Mountains, eastern, reconnaissance (W. N. Sharp, D)

San Juan Mountains, northwestern (F. S. Fisher, D)

Montana, Wickes district (W. B. Myers, D)

**Nevada:**

Comstock district (D. H. Whitebread, M)

Cortez window and vicinity (J. D. Wells, D)

Silver Peak Range (R. P. Ashley, M)

**Utah:**

East Tintic district (H. T. Morris, M)

Park City district (C. S. Bromfield, D)

Wisconsin, lead-zinc (W. S. West, Platteville)

**Limnology:**

Biological and chemical effects of impoundment, Nederlo Creek (P. A. Kammerer, w, Madison, Wis.)

Interrelations of aquatic ecology and water quality (K. V. Slack, w, M)

Theoretical study of circulation of lakes (A. Ogata, w, M)

Thermal and biological characteristics of lakes (R. G. Lipscomb, w, St. Louis, Mo.)

**New York:**

Hydrochemistry of Oneida Lake basin (F. J. Pearson, Jr., w, W)

Statewide, physical, chemical, and biologic characteristics of lakes (P. E. Greeson, w, Albany)

*See also* Contamination, water; Quality of water.

**Low flow and flow duration:**

Florida, frequency studies (R. C. Heath, w, Ocala)

Georgia, statewide (R. F. Carter, w, Atlanta)

Illinois, partial-record investigation (C. R. Sieber, w, Champaign)

Indiana, low-flow characteristics (R. E. Hoggatt, Indianapolis)

Iowa, frequency studies (H. H. Schwob, w, Iowa City)

Kansas, low flow in streams (D. V. Richards, w, Lawrence)

Maryland, flood and low-flow frequency curves and flow duration curves (P. N. Walker, w, Towson)

Massachusetts (G. K. Wood, w, Boston)

Minnesota, low-flow characteristics of Minnesota streams (J. H. Hess, w, St. Paul)

Missouri, seasonal distribution and base-flow recession (J. Skelton, w, Rolla)

New Jersey (E. G. Miller, w, Trenton)

New York, low-flow frequency (O. P. Hunt, w, Albany)

South Carolina, low-flow characteristics, coastal plain (F. A. Johnson, w, Columbia)

Washington (E. G. Nassar, w, Tacoma)

**Wisconsin:**

Low-flow character of small streams (R. W. Devaul, w, Madison)

Low-flow study (W. A. Gebert, w, Madison)

Lunar geology. *See* Extraterrestrial studies.

**Manganese.** *See* Ferro-alloy metals.

**Industrial minerals:**

- Ultramafic rocks of the Southeast (D. M. Larrabee, W)
- See also* specific minerals.

**Iron:**

- Resource studies, United States (H. Klemic, W)
- Michigan:
  - Gogebic County, western part (R. G. Schmidt, W)
  - Gogebic Range, eastern (V. A. Trent, W)
  - Negaunee and Palmer quadrangles (J. E. Gair, D)
  - Western Negaunee quadrangle (L. D. Clark, M)
- Missouri (P. W. Guild, W)
- South Dakota, northern Black Hills (R. W. Bayley, M)
- Wisconsin, Black River Falls (H. Klemic, W)

**Isotope and nuclear studies:**

- Carbon isotope geochemistry of water in Magothy Formation, Long Island, N.Y. (F. J. Pearson, Jr., w, W)
- Instrument development (F. J. Jurceka, D)
- Isotope ratios in rocks and minerals (I. Friedman, D)
- Isotopic hydrology (F. J. Pearson, w, W)
- Lead isotopes and ore deposits (R. E. Zartman, D)
- Mass spectrometry and isotopic measurements (J. Stacey, D)
- Nuclear irradiation (C. M. Bunker, D)
- Nuclear reactor facility (C. P. Kroker, w, D)
- Stable isotopes and ore genesis (R. O. Rye, D)
- Upper mantle studies (M. Tatsumoto, D)
- See also* Geochronology; Radioactive materials, transport in water; Radioactive-waste disposal.

**Land subsidence:**

- California, San Joaquin Valley (J. F. Poland, w, Sacramento)

**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-Chukchi 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)

**Marine geology--Continued**

**California--Continued**

- Continental margin, central part (J. E. Schoellhamer, M)
- 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 (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. Snively, Jr., M)
- Oregon-California, black sands (H. E. Clifton, M; G. W. Moore, La Jolla, Calif.)
- Oregon-Washington, nearshore (P. D. Snively, 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 (H. J. Freiburger, 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 (J. F. Santos, w, Tacoma)
- Washington-Oregon, movement of radionuclides in the Columbia River estuary (D. W. Hubbell, w, Portland, Ore.)
- 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:**

- Colorado, central, geologic control of ore deposits (O. L. Tweto, 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 volcanoclastic 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:
  - Agua Tibia Primitive Area, Calif. (P. Irwin, M)
  - Beartooth Primitive Area, Mont. and Wyo. (F. S. Simons, D)

**Mineral and fuel resources--Continued****Mineral resources surveys--Continued****Primitive and Wilderness Areas--Continued**

- Gila Primitive Area, N. Mex. (J. C. Ratté, D)
- Glacier Primitive Area, Wyo. (H. C. Granger, D)
- Gore Range-Eagle Nest Primitive Area, Colo. (O. L. Tweto, D)

- Idaho Primitive Area, Idaho (F. W. Cater, D)
- Salmon River Breaks Primitive Area, Idaho (P. Weis, Spokane, Wash.)

- Salmon-Trinity Alps Primitive Area, Calif. (P. E. Hotz, M)

- Wilson Mountains Primitive Area, Colo. (C. S. Bromfield, D)

- Puerto Rico (D. P. Cox, Santurce)

- Southeastern United States (R. A. Laurence, Knoxville, Tenn.)

- Yukon-Taiya area, Alaska (A. E. Weissenborn, Spokane, Wash.)

**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)****Wilderness Program, geochemical services (A. F. Marranzino, D)**

*See also* Evaporation; Limnology.

**Mineral and crystallography, experimental:****Crystal chemistry (M. Ross, W)****Crystal structure, sulfides (H. T. Evans, Jr., W)****Diagenesis of feldspars (R. W. Luce, M)****Electrochemistry of minerals (M. Sato, W)****Mineralogic services and research (M. L. Smith, W; A. J. Gude, D)****Mineralogy of heavy metals (F. A. Hildebrand, D)**

*See also* Geochemistry, experimental.

**Minor elements:****Geochemistry (G. Phair, W)****Niobium:**

- Colorado, Wet Mountains (R. L. Parker, D)

- Niobium and tantalum, distribution in igneous rocks (D. Gottfried, W)

- Phosphoria Formation, stratigraphy and resources (R. A. Gulbrandsen, M)

- Rare-earth elements, resources and geochemistry (J. W. Adams, D)

- Tantalum-niobium resources of the United States (R. L. Parker, D)

- Trace-analysis methods, research (F. N. Ward, D)

**Model studies, hydrologic. *See* Water resources; Hydrologic instrumentation.****Molybdenum. *See* Ferro-alloy metals.****Moon studies. *See* Extraterrestrial studies.****Nickel. *See* Ferro-alloy metals.****Nuclear explosions, geology:**

- Alaska Supplemental Test Site, Amchitka and Rat Islands (F. A. McKeown, D)

- Mechanism of collapse (F. N. Houser, D)

- Nevada Test Site, geologic effects analysis (F. A. McKeown, D)

- Nevada Test Site, geophysics (R. D. Carroll, D)

**Nuclear explosions, hydrology:**

- Hydrologic studies of small nuclear test sites (P. T. Voegeli, w, D)

**Nuclear explosions, hydrology--Continued**

- Hydrology in nuclear-explosive underground engineering (J. E. Weir, Jr., w, D)

- Hydrology of Amchitka Island Test Site, Alaska (W. C. Ballance, w, D)

- Hydrology of Central Nevada Test Site (G. A. Dinwiddie, w, D)

- Hydrology of Nevada Test Site (R. K. Blankennagel, w, D)
- Mississippi, Tatum salt dome area, water-resources evaluation (R. E. Taylor, w, Jackson)

**Oil shale:**

- Mineralogy (E-an Zen, W)

- Oil-shale petrology (J. R. Dyni, D)

- Oil-shale resources of the United States (D. C. Duncan, W)

- Organic geochemistry (R. E. Miller, D)

**Colorado:**

- East-central Piceance Creek Basin (R. B. O'Sullivan, D)

- Little Snake River (E. J. McKay, D)

- Piceance Creek basin (J. R. Donnell, D)

- Rangely NE quadrangle (H. L. Cullins, c, D)

- State resources (D. C. Duncan, W)

- Utah, oil shale (W. B. Cashion, Jr., D)

**Wyoming:**

- Green River Formation, Sweetwater County (W. C. Culbertson, D)

- La Barge 1 SW and 2 SE quadrangles (R. L. Rioux, c, W)

- Washakie Basin (H. W. Roehler, D)

- Wyoming-Colorado, Eocene rocks (H. W. Roehler, D)

**Paleobotany, systematic:**

- Diatom studies (G. W. Andrews, W)

**Floras:**

- Cenozoic, Pacific Northwest (J. A. Wolfe, M)

- Cenozoic, Western United States, and Alaska (J. A. Wolfe, M)

- Devonian (J. M. Schopf, Columbus, Ohio)

- Paleozoic (S. H. Mamay, W)

- Fossil wood and general paleobotany (R. A. Scott, D)

**Plant microfossils:**

- Cenozoic (E. B. Leopold, D)

- Mesozoic (R. H. Tschudy, D)

- Paleozoic (R. M. Kosanke, D)

**Paleoecology:**

- Faunas, Late Pleistocene, Pacific coast (W. O. Addicott, M)

**Foraminifera:**

- Cenozoic, larger forms (K. N. Sachs, Jr., W)

- Ecology (M. R. Todd, W)

- Recent, eastern Pacific (P. J. Smith, M)

- Ostracodes, Recent, North Atlantic (J. E. Hazel, W)

- Paleoenvironment studies, Miocene, Atlantic Coastal Plain (T. G. Gibson, W)

- Pollen, Recent distribution studies (E. B. Leopold, D)

- Tempskya*, Southwestern United States (C. B. Read, Albuquerque, N. Mex.)

- Vertebrate faunas, Ryukyu Islands, biogeography (F. C. Whitmore, Jr., W)

**Paleontology, invertebrate, systematic:****Brachiopods:**

- Carboniferous (M. Gordon, Jr., W)

- Ordovician (R. B. Neuman, W; R. J. Ross, Jr., D)

- Permian (R. E. Grant, W)

- Upper Paleozoic (J. T. Dutro, Jr., W)

**Bryozoans:**

- Ordovician (O. L. Karklins, W)

- Upper Paleozoic (H. M. Duncan, W)

**Paleontology, invertebrate, systematic--Continued**

- Cephalopods:**  
 Cretaceous (D. L. Jones, M)  
 Jurassic (R. W. Imlay, W)  
 Upper Cretaceous (W. A. Cobban, D)  
 Upper Paleozoic (M. Gordon, Jr., W)  
 Chitinozoans, Low Paleozoic (J. M. Schopf, Columbus, Ohio)  
 Conodonts, Paleozoic (J. W. Huddle, W)  
 Corals, rugose:  
 Mississippian (W. J. Sando, W)  
 Silurian-Devonian (W. A. Oliver, Jr., W)  
**Foraminifera:**  
 Fusuline and orbitoline (R. C. Douglass, W)  
 Cenozoic (R. Todd, W)  
 Cenozoic, California and Alaska (P. J. Smith, M)  
 Mississippian (B. A. L. Skipp, D)  
 Pennsylvanian-Permian, fusuline (L. G. Henbest, W)  
 Recent, Atlantic shelf (T. G. Gibson, W)  
 Tertiary, larger (K. N. Sachs, Jr., W)  
**Gastropods:**  
 Mesozoic (N. F. Sohl, W)  
 Miocene-Pliocene, Atlantic coast (T. G. Gibson, W)  
 Paleozoic (E. L. Yochelson, W)  
 Graptolites, Ordovician-Silurian (R. J. Ross, Jr., D)  
 Mollusks, Cenozoic, Pacific coast (W. A. Addicott, M)  
 Ostracodes: Lower Paleozoic (J. M. Berdan, W)  
 Upper Cretaceous and Tertiary (J. E. Hazel, W)  
 Upper Paleozoic (I. G. Sohn, W)  
**Pelecypods:**  
 Inoceramid (D. L. Jones, M)  
 Jurassic (R. W. Imlay, W)  
 Paleozoic (J. Pojeta, Jr., W)  
 Triassic (N. J. Silberling, M)  
 Radiolaria (K. N. Sachs, Jr., W)  
 Trilobites, Ordovician (R. J. Ross, Jr., D)  
**Paleontology, stratigraphic:**  
**Cenozoic:**  
 Coastal plains, Atlantic and Gulf (D. Wilson, W)  
 Diatoms, Great Plains, nonmarine (G. W. Andrews, W)  
 Foraminifera, smaller, Pacific Ocean and islands (M. R. Todd, W)  
 Mollusks:  
 Atlantic coast, Miocene (T. G. Gibson, W)  
 Pacific coast, Miocene (W. O. Addicott, M)  
 Pollen and spores, Kentucky (R. H. Tschudy, D)  
**Vertebrates:**  
 Pleistocene (G. E. Lewis, D)  
 Atlantic coast (F. C. Whitmore, Jr., W)  
 Pacific coast (C. A. Repenning, M)  
 Panama Canal Zone (F. C. Whitmore, Jr., W)  
**Mesozoic:**  
 Pacific coast and Alaska (D. L. Jones, M)  
**Cretaceous:**  
 Alaska (D. L. Jones, M)  
**Foraminifera:**  
 Alaska (H. R. Bergquist, W)  
 Atlantic and Gulf Coastal Plains (H. R. Bergquist, W)  
 Pacific coast (R. L. Pierce, M)  
 Gulf coast and Caribbean (N. F. Sohl, W)  
 Molluscan faunas, Caribbean (N. F. Sohl, W)  
 Western interior United States (W. A. Cobban, D)  
 Jurassic, North America (R. W. Imlay, W)

**Paleontology, stratigraphic--Continued**

- Mesozoic--Continued**  
 Triassic, marine faunas and stratigraphy (N. J. Silberling, M)  
**Paleozoic:**  
 Fusuline Foraminifera, Nevada (R. C. Douglass, W)  
 Mississippian biostratigraphy, Alaska (A. K. Armstrong, M)  
 Onesquethaw Stage (Devonian), stratigraphy and rugose corals (W. A. Oliver, W)  
 Paleobotany and coal studies, Antarctica (J. M. Schopf, Columbus, Ohio)  
 Palynology of cores from Naval Petroleum Reserve No. 4 (R. A. Scott, D)  
 Subsurface rocks, Florida (J. M. Berdan, W)  
 Type Morrow Series, Washington County, Ark. (L. G. Henbest, W)  
**Ordovician:**  
 Bryozoans, Kentucky (O. L. Karklins, W)  
 Stratigraphy and brachiopods, Eastern United States (R. B. Neuman, W)  
 Western United States (R. J. Ross, Jr., D)  
**Silurian-Devonian:**  
 Corals, Northeastern United States (W. A. Oliver, Jr., W)  
 Great Basin and Pacific coast (C. W. Merriam, M)  
 Upper Silurian-Lower Devonian, Eastern United States (J. M. Berdan, W)  
**Mississippian:**  
 Corals, Alaska (H. M. Duncan, W)  
 Stratigraphy and brachiopods, northern Rocky Mountains and Alaska (J. T. Dutro, Jr., W)  
 Stratigraphy and corals, northern Rocky Mountains (W. J. Sando, W)  
**Pennsylvanian:**  
**Fusulinidae:**  
 Alaska (R. C. Douglass, W)  
 North-central Texas (D. A. Myers, D)  
 Spores and pollen, Kentucky (R. M. Kosanke, D)  
**Permian:**  
 Floras, Southwestern United States (S. H. Mamay, W)  
 Stratigraphy and brachiopods:  
 Alaska (R. E. Grant, W)  
 Southwestern United States (R. E. Grant, W)  
 Upper Paleozoic, Western States (M. Gordon, Jr., W)  
**Paleontology, vertebrate, systematic:**  
 Artiodactyls, primitive (F. C. Whitmore, Jr., W)  
 Pleistocene fauna, Big Bone Lick, Ky. (F. C. Whitmore, Jr., W)  
 Soricidae (C. A. Repenning, M)  
 Tritylodonts, American (G. E. Lewis, D)  
**Paleotectonic maps. See** Regional studies and compilations.  
**Peat, Northeastern States** (C. C. Cameron, W)  
**Petroleum and natural gas:**  
 Oil and gas resources of the United States (S. P. Schweinfurth, W)  
 Organic geochemistry (J. G. Palacas, D)  
 Principles in petroleum resource estimates (W. W. Mallory, D)  
 Williston basin, Wyoming, Montana, North Dakota, South Dakota (C. A. Sandberg, D)  
 Alaska Cook Inlet basin (J. C. Maher, M)  
**California:**  
 Eastern Los Angeles basin (T. H. McCulloh, M)

**Petroleum and natural gas--Continued**
**California--Continued**

Elk Hills (R. J. Lantz, Bakersfield)

Salinas Valley (D. L. Durham, M)

**Colorado:**

Grand Junction 2-degree quadrangle, (W. B. Cashion, D)

Mellen Hill quadrangle (H. L. Cullins, c, D)

Northwestern part, Upper Cretaceous stratigraphy (J. R. Gill, D)

Rangely 7½-minute and Rangely NE quadrangles (H. L. Cullins, c, Meterie, La.)

Savery quadrangle (C. S. V. Barclay, c, D)

Mississippi, Homochitto National Forest (E. L. Johnson, c, Tulsa, Okla.)

**New Mexico:**

San Juan basin (E. R. Landis, D)

Undifferentiated formations of Silurian and Devonian age (R. R. Cunningham, c, Roswell)

North Dakota, White Butte 15-minute quadrangle (K. S. Soward, c, Great Falls, Mont.)

**Utah:**

Canaan Peak quadrangle (W. E. Bowers, c, D)

Collet Top quadrangle (H. D. Zeller, c, D)

Grand Junction 2-degree quadrangle (W. B. Cashion, D)

Northeastern part, Upper Cretaceous stratigraphy (J. R. Gill, D)

Upper Valley quadrangle (W. E. Bowers, c, D)

**Wyoming:**

Browns Hill quadrangle (C. S. V. Barclay, c, D)

LaBarge 1 SW and 2 SE quadrangles (R. L. Rioux, c, W)

Lander area phosphate reserve (W. L. Rohrer, c, D)

Haystack Mountains (E. A. Merewether, D)

Lamont-Baroil area (M. W. Reynolds, D)

Oil Mountain quadrangle (W. H. Laraway, c, Casper)

Poison Spider quadrangle (W. H. Laraway, c, Casper)

Reid Canyon quadrangle (W. H. Laraway, c, Casper)

Savery quadrangle (C. S. V. Barclay, c, D)

Spence-Kane area (R. L. Rioux, c, W)

Square Top Butte quadrangle (W. H. Laraway, c, Casper)

Taylor Mountain quadrangle (M. L. Schroeder, c, D)

Upper Cretaceous regional stratigraphy (J. R. Gill, D)

**Phosphate:**

Mineralogy (B. M. Madsen, M)

Phosphoria Formation, stratigraphy and resources (R. A. Gulbrandsen, M)

Southeastern United States, phosphate resources (J. B. Cathcart, D)

California, Monterey Formation (H. D. Gower, M)

Florida, land-pebble phosphate deposits (J. B. Cathcart, D)

**Idaho:**

Palisades Dam quadrangle (D. A. Jobin, c, D)

Palisades Peak quadrangle (D. A. Jobin, c, D)

Palisades Reservoir quadrangle (H. F. Albee, c, Salt Lake City, Utah)

Poker Peak quadrangle (H. F. Albee, c, Salt Lake City, Utah)

Upper Valley quadrangle (R. L. Rioux, c, W)

Montana, Wise River quadrangle (G. D. Fraser, c, D)

**Nevada:**

Montello area (L. H. Godwin, c, M)

Spruce Mountain 4 quadrangle (G. D. Fraser, c, D)

**Utah:**

Crawford Mountains (W. C. Gere, c, Los Angeles, Calif.)

Gilbert Peak 1 NE quadrangle (J. R. Dyni, c, D)

Morgan quadrangle (T. E. Mullens, c, D)

**Phosphate--Continued**
**Utah--Continued**

Ogden 4 NW quadrangle (R. J. Hite, c, D)

Phil Pico Mountain quadrangle (J. R. Dyni, c, D)

Vernal phosphate area (E. M. Schell, c, Billings, Mont.)

**Wyoming:**

Clause Peak quadrangle (M. L. Schroeder, c, D)

Ferry Peak quadrangle (D. A. Jobin, c, D)

Jackson 7½-minute quadrangle (H. F. Albee, c, Salt Lake City, Utah)

Lander area phosphate reserve (W. L. Rohrer, c, D)

Observation Peak quadrangle (H. F. Albee, c, Salt Lake City, Utah)

Palisades Peak quadrangle (D. A. Jobin, c, D)

Palisades Reservoir quadrangle (H. F. Albee, c, Salt Lake City, Utah)

Pine Creek quadrangle (D. A. Jobin, c, D)

Taylor Mountain quadrangle (M. L. Schroeder, c, D)

**Petrology.** *See* Geochemistry and petrology.

**Plant ecology:**

Basic research in vegetation and hydrology (R. S. Sigafos, w, W)

Hydrologic phenomena associated with vegetation changes, Boco Mountain, Colo. (G. C. Lusby, w, D)

Periodic plant-growth phenomena and hydrology (R. L. Phipps, w, W)

Plants as indicators of hydrologic environment (F. A. Branson, w, D)

Vegetation changes in southwestern North America (R. M. Turner, w, Tucson, Ariz.)

*See also* Evapotranspiration; Geochronology; Limnology.

**Platinum:**

Montana, Stillwater Complex (N. J. Page, M)

Wyoming, Medicine Bow Mountains (M. E. McCallum, Fort Collins, Colo.)

**Potash:**

Colorado and Utah, Paradox basin (R. B. Raup, W)

New Mexico, Carlsbad, potash and other saline deposits (C. L. Jones, M)

**Primitive areas.** *See under* Mineral and fuel resources—compilations and topical studies, mineral-resources surveys.

**Public and industrial water supplies.** *See* Quality of water; Water resources.

**Quality of Water:**

Reaeration in open-channel flow (R. E. Rathbun, w, Fort Collins, Colo.)

**Alaska:**

Quality of water analyses (B. Irelan, w, Anchorage)

Statewide stream quality of water and (or) temperature (H. Hulsing, w, Anchorage)

Statewide stream sediment discharge (H. Hulsing, w, Anchorage)

Arkansas, water-quality data study (J. H. Hubble, w, Little Rock)

**California:**

Base of fresh water, San Joaquin Valley (R. W. Page, w, Sacramento)

Clear Lake, nutrient study (W. D. Silvey, w, Sacramento)

Geochemical reappraisal, Fresno County (G. L. Bertoldi, w, Sacramento)

Network design, quality monitoring, Lake Siskiyou (W. D. Silvey, w, Sacramento)

Rapid determination of biological oxygen demand (J. W. Helms, w, Sacramento)



**Quality of water--Continued****California--Continued**

Sacramento-San Joaquin River, nutrients (W. D. Silvey, w, Sacramento)

Trace elements, Santa Clara Valley (R. C. Averett, w, M)

**Florida:**

Chemical characteristics of Florida streams (M. I. Kaufman, w, Tallahassee)

Hydrology of sanitary land-fill areas (J. W. Stewart, w, Tampa)

Nutrient enrichment of Lake Okeechobee (B. F. Joyner, w, Ocala)

Selected canals, Broward County (C. B. Sherwood, w, Miami)

Indiana, saline-water resources (R. A. Pettijohn, w, Indianapolis)

**Kansas:**

Cedar Bluff Irrigation District (R. B. Leonard, w, Lawrence)

South Fork Ninescah River basin (A. M. Diaz, w, Lawrence)

Kentucky, quality of surface and ground water--statewide inventory (H. C. Beaber, w, Louisville)

Louisiana, mixing characteristics of lower Mississippi River (D. E. Everett, w, Baton Rouge)

**Maryland:**

Appraisal of acid water sources in western Maryland (E. F. Hollyday, w, Towson)

Extent of brackish water in tidal rivers (S. G. Heidel, w, Towson)

Missouri, trace elements in water (G. L. Feder, w, Rolla)

Nebraska, statistical analysis of surface-water quality (K. A. Mac Kichan, w, Lincoln)

**New Jersey:**

Aeration capacity of streams (O. O. Williams, w, Trenton)

Passaic River basin, water-quality and streamflow characteristics (P. W. Anderson, w, Trenton)

Raritan River basin, water-quality and streamflow characteristics (P. W. Anderson, w, Trenton)

New Mexico, chemical-sediment basic records (K. Ong, J. D. Dewey, w, Albuquerque)

New York, Long Island, preliminary evaluation (P. Cohen, w, Mineola)

North Carolina, chemical quality of surface waters in North Carolina (H. B. Wilder, w, Raleigh)

Oklahoma, Keystone Reservoir (R. P. Orth, w, Oklahoma City)

Oregon, Umpqua River basin, surface water (D. A. Curtiss, w, Portland)

**Pennsylvania:**

Delaware River, chemical characteristics (R. W. Paulson, w, Philadelphia)

Effect of physical water quality on sedimentation in the Upper Delaware Bay (F. L. Schaefer, w, Philadelphia)

Monongahela River basin, water quality of streams (E. F. McCarren, w, Philadelphia)

Neshaminy Creek basin, quality of surface water (E. F. McCarren, w, Philadelphia)

Pesticide contributions from forested, agricultural, and urban areas (J. F. Truhlar, Jr., w, Harrisburg)

Reconnaissance of water quality of Pennsylvania impounded waters (A. N. Ott, w, Harrisburg)

Water quality of the lower Delaware River (T. E. White, w, Philadelphia)

**Quality of water--Continued****Pennsylvania--Continued**

Hubbard Creek basin (L. S. Hughes, w, Austin)

Statewide surface water (L. S. Hughes, w, Austin)

**Utah:**

Chemical changes in Great Salt Lake (R. J. Madison, w, Salt Lake City)

Reconnaissance of water-quality characteristics of surface waters in the Bear River basin (K. M. Waddell, w, Salt Lake City)

Water quality in Flaming Gorge Reservoir (R. J. Madison, w, Salt Lake City)

**Virginia:**

James River basin, water quality and streamflow characteristics (S. M. Rogers, w, Richmond)

Statistical analysis of water-quality records for Virginia (S. M. Rogers, w, Richmond)

Washington, statewide quality of surface water (N. F. Leibbrand, w, Tacoma)

**Wyoming:**

Platte River basin, surface and ground water (District staff, w, Cheyenne)

Selenium in ground water near Casper, Natrona County (M. A. Crist, w, Cheyenne)

*See also* Geochemistry; Hydrology, surface water; Limnology; Low flow and flow duration; Marine hydrology; Model studies, hydrologic; Public and industrial water supplies; Sedimentation; Water resources.

**Quicksilver.** *See* Mercury.

**Radioactive materials, transport in water:**

Movement of radionuclides, Columbia River estuary (D. W. Hubbell, w, Portland, Oreg.)

*See also* Geochemistry, water.

**Radioactive-waste disposal:****Hydrogeologic studies:**

Hydrologic studies of basalt and related rocks underlying Hanford AEC site, Richland, Wash., (A. M. LaSala, Jr., w, Richland)

Idaho, National Reactor Testing Station (J. T. Barraclough, w, Idaho Falls)

New Mexico, waste-contamination studies, Los Alamos (T. E. Kelly, w, Albuquerque)

**South Carolina:**

Savannah River Plant (I. W. Marine, w, Columbia)

Savannah River Plant, tank farm hydrology project (W. E. Clark, w, Columbia)

*See also* Geochemistry, water.

**Rare-earth metals. *See* Minor elements.****Regional studies and compilations, large areas of the United States:**

Basement rock map (R. W. Bayley, M)

Military intelligence studies (M. J. Terman, W)

**Paleotectonic-map folios:**

Mississippian System (L. C. Craig, D)

Pennsylvanian System (E. D. McKee, D)

**Remote sensing:**

Geologic applications. *See under* Geophysics, regional.

**Hydrologic applications:**

Applications to ground-water research (D. A. Phoenix, w, M)

Connecticut, Connecticut River estuary (F. H. Ruggles, Jr., w, Hartford)

Maryland, Delmarva Peninsula, (E. F. Hollyday, w, Towson)

**Remote sensing--Continued****Hydrologic applications--Continued****New Jersey:**

Barnegat Bay, vicinity of Oyster Creek (P. W. Anderson, w, Trenton)

Raritan River, between Manville and New Brunswick (P. W. Anderson, w, Trenton)

New York, lakes in central part of State (J. M. Whipple, w, Albany)

**Reservoirs.** *See* Evaporation and Sedimentation, reservoirs.

**Rhenium.** *See* Minor elements and Ferro-alloy metals.

**Saline minerals:**

Mineralogy (B. M. Madsen, M)

Colorado, Piceance Basin (D. A. Brobst, D)

Colorado and Utah, Paradox basin (R. B. Raup, W)

Nevada, Coaldale 30-minute quadrangle area (L. H. Godwin, c, M)

**New Mexico:**

Carlsbad potash and other saline deposits (C. L. Jones, M)

Salt and potash deposits of the Permian Formations of New Mexico (B. R. Alto, c, Salt Lake City, Utah)

Wyoming, Sweetwater County, Green River Formation (W. C. Culbertson, D)

Availability of fresh and saline ground water in the Rio Grande basin of Colorado, New Mexico, and Texas—a pilot study (T. E. Kelly, L. A. Hershey, B. N. Myers, w, Albuquerque, N. Mex.)

Saline ground water of the United States (F. A. Kohout, w, W)

Saline water resources and potential use in the Tularosa basin, New Mexico (J. S. McLean, w, Albuquerque)

Water in the central limestone region of St. Croix, U.S. Virgin Islands (T. M. Robison, w, San Juan, P.R.)

**Salt-water intrusion:**

California, ground water, Orange County analog model (W. F. Hardt, w, Garden Grove)

Florida, Dade County and city of Miami (C. B. Sherwood, w, Miami)

**Georgia:**

Brunswick area (D. O. Gregg, w, Brunswick)

Savannah area (H. B. Counts, w, Atlanta)

Puerto Rico, salinity reconnaissance and monitoring system, south coast (J. R. Diaz, w, San Juan)

Washington, reconnaissance of sea-water encroachment (K. L. Walters, w, Tacoma)

*See also* Marine hydrology; Quality of water.

**Sedimentation:**

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)

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)

Fluvial sediment transport to San Francisco Bay (G. Porterfield, w, M)

**Sedimentation--Continued****California--Continued**

Geologic implications of sediment, Eel River (K. M. Scott, w, M)

Glendora mudflows (K. M. Scott, w, Garden Grove)

Sand transport, Colusa Weir (D. L. Kresch, w, Sacramento)

Sediment character of California streams (B. L. Jones, w, Sacramento)

Sediment in western tributaries of Sacramento River (B. L. Jones, w, Sacramento)

**Sediment transport:**

Russian River (J. R. Ritter, w, M)

Redwoods National Park (J. R. Ritter, w, M)

South coast streams (C. Kroll, w, Garden Grove)

Sediment yield, Trinity River (J. M. Knott, w, M)

Turbidity for computing sediment (B. L. Jones, w, Sacramento)

Colorado, Badger Wash area, effect of grazing exclusion (G. C. Lusby, w, D)

Indiana, reconnaissance of sediment yields in streams (R. F. Flint, w, Columbus, Ohio)

Louisiana, Bayou Lafourche channel building processes (W. H. Doyle, w, Baton Rouge)

**Montana:**

Sedimentation in Little Prickly Pear Creek (A. R. Gustafson, w, Worland, Wyo.)

Streamflow, sedimentation, and temperature, Bluewater Creek basin (J. R. Knapton, w, Helena)

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:**

Mechanics of flow and sediment transport in Rio Grande conveyance channel near Bernardo (C. H. Scott, w, Albuquerque)

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)
- Georgia, North Fork Broad River, subwatershed 14 near Avalon (E. J. Tharpe, w, Atlanta)
- 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)
- Thermal conductivity of soil, instruments (C. R. Daum, w, d)
- See also* Evapotranspiration.

# 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)

# Springs:

- Missouri (A. Homyk, w, Rolla)
- Utah (J. C. Mundorff, w, Salt Lake City)
- See also* Marine hydrology.

# Stratigraphy and sedimentation:

- Alaska Cretaceous (D. L. Jones, M)
- East-coast Continental Shelf and Margin (R. H. Meade, Jr., Woods Hole, Mass.)
- Louisiana Continental Shelf (H. L. Berryhill, Jr., Corpus Christi, Tex.)
- Lower Paleozoic, Arizona and New Mexico (P. T. Hayes, D)
- Middle and Late Tertiary history, Northern Rocky Mountains and Great Plains (N. M. Denson, D)
- Paleozoic rocks, Ruby Range, Montana (E. T. Ruppel, D)
- Phosphoria Formation, stratigraphy and resources (R. A. Gulbrandsen, M)
- Pierre Shale, chemical and physical properties, Montana, North Dakota, South Dakota, Wyoming, and Nebraska (H. A. Tourtelot, D)
- Regional synthesis, Gulf Coastal Plain and Continental Shelf (J. C. Maher, M)
- Sedimentary petrology laboratory (H. A. Tourtelot, D)
- Sedimentary structures, model studies (E. D. McKee, D)
- Southwest basin and range Tertiary stratigraphy, Utah-California-Nevada (F. N. Houser, D)
- Texas Continental Shelf (K. A. Dickinson, Corpus Christi, Tex.)
- Williston basin, Wyoming, Montana, North Dakota, South Dakota (C. A. Sandberg, D)
- Arizona, Hermit and Supai Formations (E. D. McKee, D)
- Colorado:
  - Jurassic stratigraphy (G. N. Pipiringos, D)
  - Upper Cretaceous stratigraphy (J. R. Gill, D)
- Nebraska, central Nebraska basin (G. E. Prichard, D)
- Nevada:
  - Roberts Mountains Formation (T. E. Mullens, D)
  - Stratigraphy and composition of the Roberts Mountains Formation (T. E. Mullens, D)
- Oregon-California:
  - Black sands (H. E. Clifton, M)

# Stratigraphy and sedimentation--Continued

## Oregon-California--Continued

- Hydrologic investigations, black sands (P. D. Snavely, Jr., M)

## Utah:

- Northeastern part, Upper Cretaceous stratigraphy (J. R. Gill, D)

- Uinta Mountain Group, stratigraphy (C. A. Wallace, M)

## Wyoming:

- Lamont-Baroil area (M. W. Reynolds, D)
- South-central part, Jurassic stratigraphy (G. N. Pipiringos, D)
- Upper Cretaceous, regional stratigraphy (J. R. Gill, D)
- See also* Paleontology, stratigraphic, and specific areas under Geologic mapping.

# Structural geology and tectonics:

- Deformation research (S. P. Kanizay, D)
- Recurrent anticlines, Wyoming (M. W. Reynolds, D)
- Rock behavior at high temperature and pressure (E. C. Robertson, W)
- Transcurrent fault analysis, western Great Basin, Nevada-California (R. E. Anderson, D)
- See also* specific areas under Geologic mapping.

# Sulfur:

- Sulfur deposits in the Gulf Coast region (A. J. Bodenlos, W)

# Talc:

- New York, Pope Mills and Richville quadrangles (C. E. Brown, W)
- Southeastern United States, ultramafic rocks (D. M. Larrabee, W)

Tantalum. *See* Minor elements.

# Temperature studies, water:

- Diffusion of heat and matter in a turbulent flow field (R. S. McQuivey, w, Fort Collins, Colo.)
- Illinois River and Mississippi River temperature observations, Illinois (C. R. Sieber, w, Champaign)
- Missouri River, North Dakota (O. A. Crosby, w, Bismarck)
- North Carolina, surface water, temperature of streams (R. M. Burton, w, Raleigh, N.C.)
- Thermal loading of reservoirs and streams (G. E. Harbeck, Jr., w, D)
- Upper Delaware River, Pennsylvania-New York-New Jersey (O. O. Williams, w, Trenton, N.J.)
- Washington, stream temperatures (M. R. Collings, w, Tacoma)
- See also* Evaporation; Limnology; Marine hydrology; Quality of water.

# Thorium:

## Colorado:

- Cochetopa area (J. C. Olson, D)
- Wet Mountains (Q. D. Singewald, Beltsville, Md.)
- Montana-Idaho, Lemhi Pass area (M. H. Staatz, D)
- Titanium, economic geology of titanium (N. Herz, W)
- Tungsten. *See* Ferro-alloy metals.

# Uranium:

- Resources of radioactive minerals (A. P. Butler, Jr., D)
- Roll-type deposits, Wyoming, Texas (E. N. Harshman, D)
- Uranium-bearing pipes, Colorado Plateau and Black Hills (C. G. Bowles, D)
- Colorado, Cochetopa Creek uranium-thorium area (J. C. Olson, D)
- Idaho, Mt. Spokane quadrangle (A. E. Weissenborn, Spokane, Wash.)

**Uranium--Continued****New Mexico:**

- Acoma area (C. H. Maxwell, D)
- Ambrosia Lake district (H. C. Granger, D)
- San Ysidro area Jurassic studies (E. S. Santos, D)
- Wingate-Thoreau district (C. T. Pierson, D)

Texas, coastal plain, geophysical and geological studies (D. H. Eargle, Austin)

Texas-New Mexico, deposits in Triassic rocks (W. I. Finch, D)

Washington, Mt. Spokane quadrangle (A. E. Weissenborn, Spokane)

**Wyoming:**

- Badwater Creek (R. E. Thaden, D)
- Gas Hills (F. C. Armstrong, Spokane, Wash.)
- Hulett Creek (C. H. Maxwell, D)
- Sagebrush Park quadrangle (L. J. Schmitt, Jr., D)

**Urban geology:**

Application of geology to urban planning, research in techniques (H. E. Simpson, D)

**California:**

- Hayward-Calaveras fault zones (D. H. Radbruch, M)
- Malibu Beach quadrangle (R. F. Yerkes, M)
- Palo Alto and San Mateo quadrangles (E. H. Pampeyan, M)
- Point Dume and Triunfo Pass quadrangles (R. H. Campbell, M)

**San Francisco Bay:**

- Marine geology (D. S. McCulloch, M)
- Sediments, engineering-geology studies (D. R. Nichols, M)

Colorado, Denver metropolitan area (R. M. Lindvall, D)

District of Columbia, Washington metropolitan area (H. W. Coulter, W)

Maryland, Washington, D.C., metropolitan area (H. W. Coulter, W)

Massachusetts, Boston and vicinity (C. A. Kaye, Boston)

South Dakota, Rapid City area (J. M. Cattermole, D)

Utah, Salt Lake City and vicinity (R. Van Horn, D)

Virginia, Washington, D.C., metropolitan area (H. W. Coulter, C. F. Withington, W)

Washington, Puget Sound Basin (D. R. Mullineaux, D)

**Urban hydrology:**

California, San Francisco Bay area, urbanization (S. E. Rantz, w, M)

Urban hydrology data and techniques (W. J. Schneider, w, W)

**Urbanization, hydrologic effects:****Effect on flood flow:**

- Kansas, Wichita area (C. O. Geiger, w, Wichita)
- Mississippi, Jackson area (B. E. Wasson, w, Jackson)
- Tennessee, Nashville-Davidson County metropolitan area (L. G. Conn, w, Nashville)

Effect on stream channels and channel deltas in estuaries, Maryland and Pennsylvania (L. B. Leopold, w, W)

Effect on stream temperature (E. J. Pluhowski, w, W)

Effect on water resources (H. P. Guy, w, Fort Collins, Colo.)

Arkansas, effect of urban development on thermal springs in Hot Springs National Park (M. S. Bedinger, w, Little Rock)

California, urbanization, Santa Ana River (C. G. Kroll, w, Garden Grove)

Florida, urban hydrology study, Bay Lake (H. G. Stangland, w, Winter Park)

**Urbanization, hydrologic effects--Continued**

Maryland, sedimentation and hydrology in Rock Creek and Anacostia River basins (W. J. Davis, w, College Park)

**Texas:**

Urban hydrology study, Bryan (P. B. Rohne, Jr., w, Austin)

Urban hydrology study, San Antonio (E. E. Schroeder, w, Austin)

Washington, metropolitan Seattle-Tacoma area (F. T. Hidaka, B. L. Foxworthy, w, Tacoma)

**Vegetation:**

Elements in organic-rich material (F. N. Ward, D)

*See also* Plant ecology.

**Volcanic-terrane hydrology:**

Columbia River Basalt (R. C. Newcomb, w, Portland, Oreg.)

*See also* Artificial recharge.

**Volcanology:**

Cauldron and ash-flow studies (R. L. Smith, W)

Volcanic ash (R. E. Wilcox, D)

Arizona, San Francisco volcanic field (J. F. McCauley, M)

California, volcanic hazards, Lassen Peak and Mt. Shasta (D. R. Crandell, D)

Colorado, east and central San Juan volcanic field, petrology (P. W. Lipman, D)

Hawaii, Hawaiian Volcano Observatory (H. A. Powers, Hawaii National Park)

Idaho, central Snake River Plain, volcanic petrology (H. E. Malde, D)

**Montana:**

Bearpaw Mountains, petrology (B. C. Hearn, Jr., W)

Wolf Creek area, petrology (R. G. Schmidt, W)

**Nevada:**

Morey Peak caldera study (W. J. Carr, D)

Paintbrush and Timber Mountain tuffs (P. W. Lipman, D)

New Mexico, Valles Mountains, petrology (R. L. Smith, W)

Oregon, Bend area, volcanics (L. C. Rowan, Flagstaff, Ariz.)

Wyoming, deposition of volcanic ash in the Mowry Shale and Frontier Formation (G. P. Eaton, D)

Water cycle, hydrologic methods in arid regions, California (S. E. Rantz, w, M)

**Water management:**

Florida, southeastern part, water-management effects (S. D. Leach, w, Tallahassee)

Maryland system planning studies (D. O'Bryan, w, W)

Tennessee, Memphis area, piezometric mapping aid to management (J. H. Criner, Jr., w, Nashville)

*See also* Nuclear explosions, hydrology.

**Water resources:**

Applications of aerial photography (W. J. Schneider, w, W)

Applications of operations research tools (D. R. Dawdy, w, Fort Collins, Colo.)

Delmarva Peninsula, Md.-Va.-Del., hydrology (E. M. Cushing, w, Towson, Md.)

Economics of accuracies in water data (J. M. Turner, w, Fort Collins, Colo.)

**Ground water:**

Ground water and geology of Great Lakes Basin (R. M. Waller, w, Madison, Wis.)

Mississippi River water export study (E. H. Boswell, w, Jackson, Miss.)

Regional ground-water study of the Ohio River basin (R. E. Bloyd, w, St. Louis, Mo.)

Lower Colorado basin, hydrology (O. J. Loeltz, w, Yuma, Ariz.)

**Water resources--Continued**

Lower Mississippi River type I framework study (E. H. Boswell, w, Jackson, Miss.)

**Public domain:**

Great basin, influence of hydrology and paleohydrology on design of land use programs (C. T. Snyder, w, M)

Pacific coast region—Water-supply exploration (R. E. Smith, w, M)

Rocky Mountain region, water-supply exploration (N. J. King, w, D)

The public domain—condition and conservation (K. R. Melin, w, D)

Western States, areal hydrology (G. C. Lusby, w, D)

Upper Brazos River basin project, Permian basin program (P. R. Stevens, w, Austin, Tex.)

**Alabama (w, Tuscaloosa):**

Hydrogeologic study of State (J. G. Newton)

Relation of oil and gas industry to water resources (M. E. Davis)

**Water resources:**

Coosa River basin, upper part (J. R. Harkins)

East-central part (L. V. Causey)

Piedmont area (J. C. Scott)

Tennessee River basin (J. R. Harkins)

Tombigbee-Black Warrior River basin, upper part (J. R. Avrett)

Urban hydrology (R. C. Christensen)

**Alaska (w, Anchorage, except as noted otherwise):****Ground water:**

National parks (C. Zenone, Anchorage; J. A. McConaghy, Juneau)

Statewide water levels (A. J. Feulner)

**Hydrology:**

Amchitka Island test site (W. C. Ballance)

Anchorage area (W. W. Barnwell)

Greater Juneau Borough (J. A. McConaghy, Juneau)

Hydrologic environment of the Trans Alaska Pipeline System (TAPS) (W. W. Emmett, W)

Hydrologic reconnaissance of streams in Cook Inlet (D. K. Stewart)

Hydrologic reconnaissance of the Taiya River valley (V. K. Berwick)

Kenai Peninsula Borough (S. H. Jones, G. S. Anderson)

Municipal water-supply investigations (District staff)

Summary of water availability (A. J. Feulner)

**American Samoa (M. M. Miller, w, Honolulu, Hawaii)****Arizona (w, Tucson):**

Hydrogeologic reconnaissance of lower Tonto Creek basin (H. H. Schumann)

**Ground water:**

Analysis of water-level declines (E. B. Hodges)

Beardsley area (W. Kam)

Big Sandy Valley (E. S. Davidson)

Coconino County, southern part (E. H. McGavock)

Electric-analog analysis of hydrologic data for Avra Valley (O. Moosburner)

Kingman area (J. B. Gillespie)

Navajo Indian Reservation (M. E. Cooley)

Reconnaissance study of water supply of Lake Mead Recreational Area (C. B. Bentley)

Safford area (E. S. Davidson)

Tucson basin (E. S. Davidson)

**Hydrology:**

Alluvial basins (M. E. Cooley)

**Water resources--Continued****Arizona (w, Tucson)--Continued****Hydrology--Continued**

Remote sensing—Gila River phreatophyte project (R. M. Turner)

**Arkansas (w, Little Rock):**

Ground water, ground-water hydrology of alluvial valleys of Arkansas and Verdigris Rivers (M. S. Bedinger)

Water resources, Hempstead, Lafayette, Little River, Miller, and Nevada Counties (A. H. Ludwig)

**California (w, Menlo Park, except as noted otherwise):****Computer technology in water-resources studies:**

Dispersion of heat in stratified flow (J. G. Weil)

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 (R. M. Bloyd)

Bartow area, continuing inventory (J. H. Koehler, Garden Grove)

Cuyama Valley appraisal (J. A. Singer, Garden Grove)

Death Valley National Monument hydrologic reconnaissance (G. A. Miller, Garden Grove)

Geohydrology of Pajaro Valley (J. P. Akers)

Ground-water network criteria (L. C. Dutcher)

Hollister-San Juan Bautista area (C. Kilburn)

Harper Valley (W. R. Moyle, Jr., Garden Grove)

Indian Wells Valley area (J. H. Koehler, Garden Grove)

Indian Wells Valley digital model (R. M. Bloyd, Jr., Garden Grove)

Ivanpah Valley (W. R. Moyle, Jr., Garden Grove)

Joshua Tree-Yucca Valley area (R. E. Lewis, Garden Grove)

Mojave River analog model (W. F. Hardt, Garden Grove)

San Luis Rey River valley (W. R. Moyle, Jr., Garden Grove)

Santa Clara Valley analog model (P. R. Wood)

Stanislaus County (R. W. Page, Sacramento)

Tracy-Dos Palos area appraisal (W. Hotchkiss, Sacramento)

Twentynine Palms area (F. W. Giessner, Garden Grove)

Upper Coachella Valley (S. J. Tyley, Garden Grove)

Upper Santa Clara River valley (S. G. Robson, Garden Grove)

Upper Santa Margarita Valley, ground-water inventory (F. W. Giessner, Garden Grove)

Vandenberg Air Force Base (F. W. Giessner, Garden Grove)

Yucaipa artificial recharge study (J. A. Moreland, Garden Grove)

**Hydrology:**

Cachuma reservoir (M. W. Busby, Garden Grove)

California comprehensive framework (S. E. Rantz)

Characteristics of California lakes (J. R. Crippen)

Hydrology of Big Bear Lake (E. G. Pearson, Garden Grove)

Perris Valley urban hydrology (M. Busby, Garden Grove)

Sequoia-Kings Canyon National Park (G. A. Le Blanc, Sacramento)

## Water resources--Continued

## California--Continued

Relation between surface water and ground water, factors determining feasibility of artificial recharge (J. Rubin)

Sedimentology, seasonal variations in composition and abundance of particulate matter suspended in waters exchanged between the San Francisco Bay and the adjacent Pacific Ocean (T. J. Conomos)

## Surface water:

Surface-water network evaluation (J. R. Crippen)

Temperature distribution in natural streams (J. C. Blodgett, Sacramento)

Surface-water hydrology, evaluation of runoff during periods of low flow (W. D. Simons)

## Colorado (w, Denver):

## Ground water:

Baca and southern Prowers Counties (L. A. Hershey)

Bent County (J. H. Irwin)

High Plains of Colorado (W. E. Hofstra)

Pueblo Army Depot (F. A. Welder)

Western Colorado (A. J. Boettcher)

## Hydrology:

Arkansas Valley, Pueblo to State line (O. J. Taylor)

San Luis Valley (P. A. Emery)

South Platte River basin, Henderson to State line (D. R. Albin)

Water resources, Rocky Mountain National Park (F. A. Welder)

## Connecticut (w, Hartford):

## Water resources:

Part 4, Southwestern coastal basins (R. B. Ryder)

Part 5, Lower Housatonic River basin (W. E. Wilson)

Part 6, Upper Housatonic River basin (M. A. Cervione, Jr.)

Part 7, Upper Connecticut River basin (R. B. Ryder)

Part 8, Quinnipiac River basin (G. R. Tarver)

## Florida (w, Tallahassee):

## Geohydrology:

Cocoa well-field area (W. F. Lichtler)

Cross-Florida Barge Canal (G. L. Faulkner)

Upper St. Johns River (D. A. Goolsby)

## Ground water:

Dade County, special studies (C. B. Sherwood)

Fort Lauderdale area, special studies (H. J. McCoy)

Hydrobiology, Loxahatchee Refuge area (M. C. Kolipinski)

## Hydrology:

Analog model, Biscayne aquifer (C. A. Appel)

Infiltration, Miami Canal (F. W. Meyer)

Model study, Hillsborough River basin (J. A. Mann)

## Remote sensing:

Alafia and Peace basins (A. E. Coker)

Everglades area (M. C. Kolipinski)

Gulf coastal area (J. D. Hunn)

West-central lakes (J. W. Stewart)

Upper Tampa Bay (J. A. Mann)

Venice well-field area (H. Sutcliffe)

Special studies, statewide (C. S. Conover, R. W. Pride)

Water atlas (E. R. Hampton)

## Water resources:

Broward County (C. B. Sherwood)

Charlotte County (H. Sutcliffe)

Clearwater-Dunedin area (R. N. Cherry)

Dania-Hallandale area (H. W. Bearden)

## Water resources--Continued

## Florida (w, Tallahassee)--Continued

## Water resources--Continued

Desoto-Hardee Counties (R. C. Reichenbaugh)

Duval County (G. W. Leve)

East-central Florida (W. F. Lichtler)

Everglades National Park (M. C. Kolipinski)

Indian River County (L. J. Crain)

Lake County (D. D. Knockenmus)

Lakeland Ridge area (A. F. Robertson)

Lee County (D. H. Boggess)

Marion County (G. L. Faulkner)

Mid-Gulf basins (R. N. Cherry)

Myakka River basin (B. F. Joyner)

Palm Beach County (H. Klein)

St. Lucie County (H. W. Bearden)

Volusia County (B. J. Bermes)

Walton County (C. A. Pascale)

Western Collier County (J. N. Crenshaw)

Yellow-Shoal Rivers area (J. B. Foster)

## Georgia (w, Atlanta):

Availability of water supplies in northwest Georgia (C. W. Cressler)

Ground water, Gordon, Murray, and Whitfield Counties (C. W. Cressler)

Hydrogeology, Pulaski, Wilcox, Crisp, Dooly, Lee, and Sumter Counties (R. C. Vorhis)

Hydrologic appraisal of the upper Cretaceous (R. C. Vorhis)

Quality of ground water (R. G. Grantham)

Special studies, statewide (A. M. F. Johnson)

## Water resources:

Colquitt County (E. A. Zimmerman)

Liberty County, Riceboro area (T. R. Dyar)

Georgia, Florida, and South Carolina, study of the principal limestone aquifer (Suwannee Strait, in part (S. M. Herrick, w, Atlanta, Ga.)

## Guam:

Water pollution, Andersen Air Force Base (H. R. Feltz, w, W)

Water resources, Andersen Air Force Base, northern Guam (D. A. Davis, w, Honolulu, Hawaii)

## Hawaii (w, Honolulu):

## Water resources:

Hawaii, water-resources reconnaissance summary (D. A. Davis)

Kauai, Waialeale, rainfall (M. M. Miller)

Maui, northeastern part, reconnaissance (K. J. Takasaki)

Maui, southeastern part, reconnaissance (K. J. Takasaki)

Maui, Wailuku area, reconnaissance (G. Yamanga)

## Oahu:

Pearl Harbor area, discharge-head relationship (R. H. Dale)

Pearl Harbor area, ground-water study (R. H. Dale)

## Idaho (w, Boise):

Surface water, Bruneau River basin, systems gaging (H. C. Riggs, W)

## Water resources:

Big Lost River basin (E. G. Crosthwaite, C. A. Thomas, K. L. Dyer)

Effects of urbanization, Boise-Nampa area (N. P. Dion)

Little Lost River basin (H. A. Waite, S. O. Decker)

Mud Lake area (P. R. Stevens)

**Water resources--Continued****Idaho (w, Boise)--Continued****Water resources--Continued**

- Portneuf River basin (R. F. Norvitch, A. L. Larson)
- Raft River basin (E. H. Walker, S. O. Decker, K. L. Dyer)
- Recharge to Rathdrum Prairie (R. E. Hammond)
- Test drilling, Snake River Plain (E. G. Crosthwaite)
- Water use inventory, Snake Plain aquifer (H. W. Young)

**Indiana (w, Indianapolis):****Analog model, upper White River basin (R. W. Maclay)****Ground water:**

- Drainage basins tributary to the Ohio River (R. A. Pettijohn)
- Kankakee and Calumet River basins (J. D. Hunn)
- St. Joseph River basin (R. A. Pettijohn)
- Wabash River basin (R. A. Pettijohn)
- Whitewater River basin (R. J. Wolf)
- Maumee River basin (R. A. Pettijohn)
- Upper Wabash River basin (C. H. Tate)
- Upper White River basin (L. W. Cable)

**Iowa (w, Iowa City):**

- Dakota aquifer appraisal (W. L. Steinhilber)
- Geology and ground-water resources, Linn County (R. E. Hasen)
- Ground-water resources of a Mississippian aquifer (W. L. Steinhilber)
- Test drilling in south-central Iowa (J. W. Cagle)
- Water availability, Muscatine Island, Muscatine County (R. E. Hansen)
- Water resources of southeast Iowa (R. W. Coble)

**Kansas (w, Lawrence):****Analysis of hydrologic data (J. M. McNellis)****Ground water:**

- Atchison County (J. R. Ward)
- Doniphan County (C. K. Bayne)
- Gove, Logan, Wallace Counties (E. D. Jenkins)
- Hamilton County (H. E. McGovern)
- Jefferson County (J. D. Winslow)
- Johnson County (H. G. O'Connor)
- Lower Arkansas, Verdigris, Neosho basins, Kansas-Oklahoma (S. W. Fader)
- Montgomery County (H. G. O'Connor)
- Nemaha County (J. R. Ward)
- Northwestern part (E. D. Jenkins)
- Pratt County (D. W. Layton)
- Rush County (J. McNellis)
- Southwestern part (H. E. McGovern)
- Washington County (C. K. Bayne)

**Water resources, Kansas Valley--Abilene to Kansas City (S. W. Fader)****Kansas and Oklahoma, ground water in Arkansas, Verdigris, and Grand River basins (S. W. Fader, w, Lawrence; R. B. Morton, w, Oklahoma City)****Kentucky (w, Louisville):****Ground water:**

- Ground water in alluvium of major Ohio River tributary streams (P. D. Ryder)
- Hydrology of buried Pennsylvanian channel sandstone (R. W. Davis)

**Water resources:**

- Bowling Green area (T. W. Lambert)
- Mammoth Cave area (R. V. Cushman)

**Water resources--Continued****Louisiana (w, Baton Rouge, except as noted otherwise):****Ground water:**

- Gramercy area (C. Kilburn)
- Hydrology of the Red River Valley (A. H. Ludwig, Little Rock, Ark.)
- Kisatchie Forest area (J. E. Rogers)
- Norco area (R. L. Hosman)
- Water quality in upper Mississippi River Delta alluvium (M. S. Whitfield)
- Water resources of terrace aquifer, central Louisiana (T. H. Sanford)

**Pumpage of water in Louisiana, 1970 (D. C. Dial)****Reports on special topics (M. F. Cook)****Surface water:**

- Drainage areas (R. Sloss)
- Quality-of-water trends in Louisiana streams (M. W. Gaydos)
- Sabine River--Toledo Bend problem studies (W. J. Shampine)
- Temperature of water in Louisiana streams (A. J. Calandro)
- Velocity of Louisiana streams (A. J. Calandro)
- Survey of Louisiana lakes and reservoirs (W. J. Shampine)
- Tangipahoa-Tchefuncte River basins (D. J. Nyman)

**Water resources:**

- Amite-Tickfaw River basins (M. D. Winner, Jr.)
- Baton Rouge area (C. D. Whiteman, Jr.)
- Little River basin (M. W. Gaydos)
- New Orleans area (C. D. Whiteman, Jr.)
- Plaquemine-White Castle area (C. D. Whiteman, Jr.)
- Site studies (R. L. Hosman)
- Southwestern part (A. L. Zack)

**Maine (w, Augusta):****Ground water:**

- Lower Aroostook basin in Maine (G. C. Prescott)
- Meduxnekeag and Prestile basins in Maine (G. C. Prescott)
- St. John basin in Maine (G. C. Prescott)

**Maryland (w, Towson, except as noted otherwise):****Ground water:**

- Aquifer research in limestone terranes, Frederick and Hagerstown Valleys (L. J. Nutter)
- Assateague Island National Seashore (E. F. Hollyday)
- Evaluation of Magothy aquifer Annapolis area (F. K. Mack, Annapolis)
- Exploration of Salisbury paleochannel (J. M. Weigle)
- Sedimentary rocks, occurrence of ground water, coastal plain (H. J. Hansen, w, State employee, Baltimore)

**Water resources:**

- Georges Creek basin, a corner of Appalachia (D. O'Bryan, w, W)
- Lower Bay counties--Calvert, Charles, and St. Marys (J. M. Weigle)

**Massachusetts (w, Boston):****Ground water:**

- Boston, central area (J. E. Cotton)
- Cape Cod National Seashore (J. E. Cotton)

**Water resources:**

- Charles River basin (E. H. Walker)
- Deerfield-Hoosic River basins (L. G. Toler)
- Nashua River basin (R. A. Brackley)



**Water resources--Continued****Massachusetts (w, Boston)--Continued****Water resources--Continued**

Neponset-Weymouth River basins (R. A. Brackley)

Southeastern coastal drainage (J. R. Williams)

Taunton River basin (J. R. Williams)

**Michigan (w, Lansing):****Ground water:**

Baraga County (G. E. Hendrickson)

Houghton-Keweenaw Counties (G. E. Hendrickson)

Hydrology of river-based recreation (G. E. Hendrickson)

**Surface water:**

Compilation of lake data (J. B. Miller)

Statistical summaries of streamflow data (R. L. Knutilla)

**Water resources:**

Clinton, Eaton, Ingham Counties (K. E. Vanlier)

Oakland County (F. R. Twenter)

River basins in southeastern Michigan (R. L. Knutilla)

Upper Rifle River basin (R. L. Knutilla)

Washtenaw County (F. R. Twenter)

Midway Islands, well sites (D. A. Davis, w, Honolulu, Hawaii)

**Minnesota (w, St. Paul):****Ground water:**

Geology and water-bearing characteristics of glacial deposits, northeastern Minnesota (T. C. Winter)

Ground water for irrigation near Little Falls (J. O. Helgesen)

Ground water for irrigation near Perham (H. O. Reeder)

Hydrology, Twin Cities metropolitan area (H. O. Reeder)

**Water budget:**

Lake Sallie (W. B. Mann IV)

Shagawa Lake (D. W. Ericson)

Water resources of the Red River of the North basin in Minnesota (T. C. Winter)

**Water-resources reconnaissance of watershed units:**

Blue Earth River (H. W. Anderson, Jr.)

Cottonwood River (H. W. Anderson, Jr.)

Crow River (G. F. Lindholm)

Hawk Creek (W. A. Van Voast)

Kettle River (G. F. Lindholm)

Lower Minnesota River (H. W. Anderson, Jr.)

Lower St. Croix River (G. F. Lindholm)

Mississippi River-Sauk River (G. F. Lindholm)

Rum River (G. F. Lindholm)

Snake River (G. F. Lindholm)

**Mississippi (w, Jackson):****Water resources:**

Amite, Franklin, Lincoln, Pike, and Wilkinson Counties (R. Newcome)

Calhoun, Chickasaw, Choctaw, Montgomery, Webster, and Yalobusha Counties (F. H. Thomson)

Clarke, Jasper, Lauderdale, Newton, Scott, and Smith Counties (E. H. Boswell)

Copiah-Simpson Counties (R. Newcome)

Harrison County (D. E. Shattles)

Jackson County (D. E. Shattles)

Kemper, Leake, Neshoba, Noxubee, and Winston Counties (E. H. Boswell)

Natchez Trace Parkway, investigations along (F. H. Thomson)

Washington County (R. E. Taylor)

**Water resources--Continued**

Mississippi River water export study, ground-water availability (E. H. Boswell, w, Jackson, Miss.)

**Missouri (w, Rolla):****Water resources:**

Northwest Missouri (E. E. Gann)

St. Louis, St. Charles, and Jefferson Counties (H. G. Jeffery)

West-central Missouri (E. E. Gann)

**Montana (w, Billings, except as noted otherwise):****Ground water:**

Central Powder River valley (W. R. Miller)

Clark Fork basin (A. W. Gosling)

Eastern Judith Basin (R. D. Feltis)

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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. M. Aaron (r0420).

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