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GEOLOGICAL SURVEY RESEARCH 1975

GEOLOGICAL SURVEY PROFESSIONAL PAPER 975

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GEOLOGICAL SURVEY PROFESSIONAL PAPER 975

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

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON, D.C.: 1975

UNITED STATES DEPARTMENT OF THE INTERIOR

THOMAS S. KLEPPE, *Secretary*

GEOLOGICAL SURVEY

V. E. McKelvey, *Director*

Library of Congress catalog-card No. 68-46150

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402
Stock Number 024-001-027747

FOREWORD

"Geological Survey Research 1975" is the 16th annual synopsis of the results of U.S. Geological Survey investigations. These studies are largely directed toward the development of knowledge that will assist the Nation to use and conserve the land and its physical resources wisely. They are wide ranging in scope and deal with almost every facet of solid-earth science and fact finding.

Many of the studies reported here are continuations of investigations that have been in progress for several years or more. But others reflect the increased attention being given to problems that have assumed greater importance in recent years—problems relating to mineral fuels and mineral resources, water quality, environmental impact of mineral resources, land-use analysis, earthquake hazards reduction, subsidence, and the applications of LANDSAT data, to cite a few examples.

These changes in program emphasis are paralleled by new developments in earth science and technology, and the two combine, as they have throughout the Survey's history, to keep these investigations dynamic in their character and direction.

V. E. McKelvey,
Director.

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ABBREVIATIONS

Abbreviation	Meaning
a-c	alternating current
AEC	Atomic Energy Commission (now Nuclear Regulatory Commission)
AID	Agency for International Development, U.S. Department of State
AIDJEX	Arctic Ice Dynamics Joint Experiment
atm	atmosphere
bbl	barrel
BOD	biochemical oxygen demand
B.P.	before present
b.y	billion years
cal	calorie
CCT	computer-compatible tape
Ci	curie
CIPW	Cross, Iddings, Pirsson, and Washington
CRIB	Computerized Resources Information Bank
CRT	cathode ray tube
d	day
dc	mean diurnal temperature
d-c	direct current
DCP	Data Collection Platform
DCS	Data Collection System
DO	dissolved oxygen
DOD	Department of Defense
DSDP	Deep Sea Drilling Project
dyn	dyne
emu	electromagnetic unit
EPA	Environmental Protection Agency
ERDA	Energy Resource and Development Administration
EREP	Earth Resources Experiment Package
EROS	Earth Resources Observation Systems
ERS	Earth Resources Survey
f.l.	focal length
g	gravity
GOES	Geostationary Operational Environmental Satellite
GRASP	Geologic Retrieval and Storage Program
h	hour
HFU	heat-flow unit
hp	horsepower
HUD	Housing and Urban Development
Hz	hertz (cycle per second)
IGC	International Geological Congress
IGU	International Geographical Union
IGY	International Geophysical Year
IHD	International Hydrological Decade
IHP	International Hydrologic Program
IUGS	International Union of Geological Sciences
J	joule
JOIDES	Joint Oceanographic Institutions Deep Earth Sampling
JTU	Jackson turbidity unit
K	kelvin
kcal	kilocalorie
KREEP	potassium, rare-earth elements, phosphorus
LANDSAT	Land Satellite (formerly ERTS)
lat	latitude
loc.	location
long	longitude
mb	millibar
MeV	megaelectronvolt
mg/l	milligram per litre, or ppm
mGal	milligal
min	minute
mo	month
mol	mole
MSS	multispectral scanner
m.y.	million years
μg/g	microgram per gram, or ppm
μg/l	microgram per litre, or ppb
μg/ml	microgram per millilitre, or ppm
μmho	micromho
NASA	National Aeronautics and Space Administration
NAWDEX	National Water Data Exchange
nm	nanometres
NOAA	National Oceanic and Atmospheric Administration
NSF	National Science Foundation
ohm-m	ohm-metre
Pa	pascale
pH	measure of hydrogen ion activity
ppb	part per billion
ppm	part per million
ppt	part per thousand
RALI	Resource and Land Information
REE	rare-earth element
rms	root mean square
s	second
SLAR	side-looking airborne radar
SMOW	standard mean ocean water
TAPS	trans-Alaska pipeline system
TVA	Tennessee Valley Authority
U.N.	United Nations
UNESCO	United Nations Educational, Scientific, and Cultural Organization
USGS	U.S. Geological Survey
USPHS	U.S. Public Health Service
UTM	Universal Transverse Mercator
V	volt
yr	year

METRIC-ENGLISH EQUIVALENTS

Metric unit		English equivalent
Length		
millimetre (mm)	= 0.03937	inch (in)
metre (m)	= 3.28	feet (ft)
kilometre (km)	= .62	mile (mi)
Area		
square metre (m^2)	= 10.76	square feet (ft^2)
square kilometre (km^2)	= .386	square mile (mi^2)
hectare (ha)	= 2.47	acres
Volume		
cubic centimetre (cm^3)	= 0.061	cubic inch (in^3)
litre (l)	= 61.03	cubic inches
cubic metre (m^3)	= 35.31	cubic feet (ft^3)
cubic metre	= .00081	acre-foot (acre-ft)
cubic hectometre (hm^3)	= 810.7	acre-feet
litre	= 2.113	pints (pt)
litre	= 1.06	quarts (qt)
litre	= .26	gallon (gal)
cubic metre	= .00026	million gallons (Mgal or 10^6 gal)
cubic metre	= 6.290	barrels (bbl) (1 bbl = 42 gal)
Weight		
gram (g)	= 0.035	ounce, avoirdupois (oz avdp)
gram	= .0022	pound, avoirdupois (lb avdp)
tonne (t)	= 1.1	tons, short (2,000 lb)
tonne	= .98	ton, long (2,240 lb)
Specific combinations		
kilogram per square centimetre (kg/cm^2)	= 0.96	atmosphere (atm)
kilogram per square centimetre	= .98	bar (0.9869 atm)
cubic metre per second (m^3/s)	= 35.3	cubic feet per second (ft^3/s)
Specific combinations—Continued		
litre per second (l/s)	= .0353	cubic foot per second
cubic metre per second per square kilometre [(m^3/s)/km^2]	= 91.47	cubic feet per second per square mile [(ft^3/s)/mi^2]
metre per day (m/d)	= 3.28	feet per day (hydraulic conductivity) (ft/d)
metre per kilometre (m/km)	= 5.28	feet per mile (ft/mi)
kilometre per hour (km/h)	= .9113	foot per second (ft/s)
metre per second (m/s)	= 3.28	feet per second
metre squared per day (m^2/d)	= 10.764	feet squared per day (ft^2/d) (transmissivity)
cubic metre per second (m^3/s)	= 22.826	million gallons per day (Mgal/d)
cubic metre per minute (m^3/min)	= 264.2	gallons per minute (gal/min)
litre per second (l/s)	= 15.85	gallons per minute
litre per second per metre [(l/s)/m]	= 4.83	gallons per minute per foot [(gal/min)/ft]
kilometre per hour (km/h)	= .62	mile per hour (mi/h)
metre per second (m/s)	= 2.237	miles per hour
gram per cubic centimetre (g/cm^3)	= 62.43	pounds per cubic foot (lb/ft^3)
gram per square centimetre (g/cm^2)	= 2.048	pounds per square foot (lb/ft^2)
gram per square centimetre	= .0142	pound per square inch (lb/in^2)
Temperature		
degree Celsius (°C)	= 1.8	degrees Fahrenheit (°F)
degrees Celsius (temperature)	= [(1.8 × °C) + 32]	degrees Fahrenheit

GEOLOGICAL SURVEY RESEARCH 1975

MINERAL-RESOURCE AND MINERAL-FUELS INVESTIGATIONS

GEOLOGY OF MINERAL OCCURRENCES

Metallogeny and global tectonic theory

P. W. Guild proposed that many apparent conflicts between theories of metallogeny such as those based on geosynclinal development, relationship to median massifs and regions of "autonomous activization," lineament control, and other factors can be resolved by principals of global tectonics. Endogenic mineral deposits can form in at least four plate environments: (1) at accreting plate margins (rift or ocean rise, ophiolite-associated deposits), (2) over subducting zones near converging margins (cordilleran, island-arc deposits), (3) above hot spots or mantle plumes in the interior of plates (Mississippi Valley and other types), or (4) in regions of continental reactivization that may result from upwelling of material from the asthenosphere behind a subducting plate of oceanic lithosphere (Great Basin and Rocky Mountain deposits of the general Laramide type). Chemical elements in ores may be derived from the mantle directly or by two-stage or multistage processes; their provenance and mode of concentration into mineral deposits differ in many ways that can be accounted for by the models proposed.

Geochemical anomalies near the Haile gold mine

Preliminary compilation of geochemical data from small streams in the Haile mine area of Kershaw and Lancaster Counties, S.C., was carried out by Henry Bell III. The data obtained by semiquantitative spectrographic analysis show that a large area low in iron coincides with the southeast-trending contact between coarse volcaniclastic rocks and overlying argillite in the Carolina slate belt. The low-iron area encloses smaller areas with anomalous tin in heavy-mineral concentrates as well as in massive pyrite bodies at the Haile mine. Gold-bearing alluvium in the same area, however, seems to reflect a pre-Triassic shear zone trending northwest between two granite plutons.

Structural control of the Hamme tungsten deposit, North Carolina

At the Hamme tungsten deposit, J. E. Gair found that the principal mineralized veins strike north-northeast, dip steeply southeast, are lenticular and en echelon, and in places have warps and buckles that plunge steeply to the south. Lenticular veins contain and are separated by seams of sericite schist, which contain small drag folds that also plunge to the south. The tungsten lodes generally are elongated steeply downward to the south in the plane of the vein system. Lodes, warps, buckles, and drag folds plunge along approximately similar axes. The flow of silica-rich solutions and the later mineralizing fluid therefore appears to have been channeled along the principal axes of warping and drag folding. Within the veins, huebnerite-sulfide-fluorite mineralization may be scattered quite irregularly but commonly is distributed along sheeting (conspicuous parting parallel to the vein walls) and along schist seams that diverge from sheeting and strike northward across the northeast-trending veins. Sheeting and schist seams were principal pathways for mineralizing fluids moving through the quartz veins. Tungsten mineralization is confined to a large westward bulge in the northwestern part of the Hamme granodiorite-tonalite pluton. The bulge may be a last stage of multiple intrusion, representing a late magma phase.

Zoned ore bodies in the Cave-in-Rock district, Illinois

Underground mapping of bedded ore bodies in the Cave-in-Rock district by D. M. Pinckney showed that the minerals form two sets of zones. Fluorite is zoned relative to calcite, fluorite occupying the central position. Sphalerite is zoned relative to barite, sphalerite occupying the central position.

The two sets of zones, fluorite-calcite and sphalerite-barite, overlap, but the boundary between minerals of one set generally does not coincide with the boundary between minerals of the other set. Characteristically, the interior of an ore body consists of fluorite and sphalerite.

Occurrences of zinc in Kansas

Library research by M. H. Miller found references (Lee, 1940, p. 78) to two occurrences of sphalerite in the Mississippian limestones of Kansas, which are the main host rocks of the tri-state zinc district deposits. The first occurrence is in a drill hole at a depth of 1415.8 to 1417.3 m in probable Burlington Limestone in sec. 16, T. 16 S., R. 28 W., Lane County, central western Kansas. The second occurrence is in sec. 17, T. 33 S., R. 6 W., southwest of Wichita, in Harper County, Kan., where sphalerite occurs associated with chert (or jasperoid?) and crystals of white calcite in the Cowley Formation at a depth of 1347.8 to 1352.4 m. Such occurrences may be related to deeply buried Mississippi Valley-type ore deposits.

Geologic setting of the Mogollon mining district, New Mexico—a reappraisal

Reappraisal of the geologic setting of the Mogollon, N. Mex., mining district based on geologic mapping and geophysics by J. C. Ratté, G. P. Eaton, D. L. Gaskill, and D. L. Peterson (1974) indicated a significant potential for discovering additional ore bodies of precious or base metals within or adjacent to the district. The Mogollon district is astride the topographic margin of the Bursum Caldera of Tertiary age and lies mainly within the structural moat between the caldera wall and a resurgent dome.

Recognition of the caldera setting of the district leads to new interpretations and correlations of the volcanic stratigraphy within the district and in adjoining parts of the Gila Wilderness and Gila Primitive Area. Most important, perhaps, has been the discovery of the intrusive relationship of the Fanney Rhyolite, both within and beyond the district. At the eastern edge of the Mogollon 7½-min quadrangle, the Fanney Rhyolite intruded older andesites and erupted through a vent to form a thick layer of pyroclastic material that previously was mapped as a younger unit. Within the district, similar crosscutting contacts of the Fanney Rhyolite previously attributed to either faulting or rough pre-Fanney topography are now considered to be intrusive contacts. These observations confirm the speculations by earlier investigators about a relationship between the distribution of the Fanney Rhyolite, the ring fracture zone of the Bursum Caldera, and mineralization in the Mogollon district. In addition to the rhyolite intrusions, several small intrusions of hornblendic, latitic, or dacitic rocks have been discovered recently within this ring fracture zone. Thus, the geologic setting seems to be favorable for extensive intrusion at depth along the ring fracture zone and particularly where the caldera margin is intersected by regional northeastern and northwestern fracture belts.

Gravity and magnetic anomalies are spatially associated with the Mogollon district, and a gravity high over the district is part of an elongate high that continues southeastward to the Silver City and Santa Rita mining districts. In a preliminary interpretation of this gravity anomaly, Eaton related it to the probable presence of Paleozoic carbonate rocks in the subsurface, which provide a density contrast with the dominant volcanic surface rocks. Calcite veins, as much as 20 m wide north of the Mogollon district, provide additional support for this interpretation. The mineral potential of the Mogollon mining district, as well as of other parts of the Bursum Caldera ring fracture zone, is enhanced by the possibility of extensive intrusion at depth along the zone and the probability of a Paleozoic carbonate section at depth adjacent to the area of intense volcanic eruptions and caldera subsidence.

Zeolite in southwestern New Mexico

Several extensive areas of rhyolitic tuff in the Winston, N. Mex., area were mapped by C. H. Maxwell. The tuff has been altered over large areas to material identified by R. A. Sheppard as being composed largely of clinoptilolite and having a good economic potential for industrial use. Resources may be of the order of 45 million tonnes.

Four auriferous gravel units in the Hillsboro Las Animas district, Sierra County, New Mexico

The western edge of the Rio Grande Trench and the fringing Las Animas Hills, near lat 33 N. in New Mexico, display four gravel units, according to Kenneth Segerstrom and J. C. Antweiler III. These are:

1. A calcite-cemented deposit that occurs in the subsurface east of the hills and in eroded remnants on the flanks of the hills. The probable age is 7 to 9 m.y. (latest Miocene or earliest Pliocene).
2. An overlapping gravel that mantles piedmont slopes descending eastward toward the Rio Grande and contains as many as four or five soil-calcite layers. This thick fill deposit is about 500,000 yr old (mid-Pleistocene).
3. A gravel unit, lenticular in cross section and with one or two buried soil-caliche layers, that partly fills shallow valleys cut in the No. 2 deposit. This

unit is of late Pleistocene and (or) early Holocene age.

4. Modern stream deposits without carbonate cement.

Vertical channel samples from trenches and stream-cut banks in units 1, 2, and 3 consistently have visible gold in pan concentrates as far as 3 km east of the Animas Hills. Gold is visible in pan concentrates from unit 4 as far as 15 km east of the Animas Hills, but not consistently.

A new cauldron subsidence feature at Silver Cliff-Johnson Gulch

A gravity study and careful consideration of surface geology by W. N. Sharp led to identifying a previously unrecognized subsidence cauldron 4.8 km northeast of Silver Cliff, Colo. At the surface, an oval-shaped depression, 1.6×2.4 km in size, is marked by thin-bedded to massive white rhyolitic water-laid tuff. This rock unit was mapped as early as 1883 by Whitman Cross (1896, p. 322) and described as ". . . a local and unimportant lake-bed deposit. The surface geology is deceptive. The tuff unit occupies a generally depressed area in the moderately dissected Precambrian gneisses. Two sides of the tuff unit are bounded by intersection faults. The low scarps of these structures and the modest-appearing offset allowed a small collecting basin to preserve the tuff beds."

The geologic evidence showing that the Precambrian gneisses are the walls of a subsided cauldron is modest but in order. The tuff beds dip inward along the contact in the few places that they can be seen. In one place, the contact is marked by a zone of coarse breccia—mostly Precambrian rocks with some volcanic blocks, tightly packed, angular, and all stained and highly weathered. This unit appears to be breccia associated with collapse. Precambrian rocks at and near the contact are fractured at many places and sufficiently iron stained to attract prospecting. At one such place the fractures are filled with black manganese-iron oxides, a common occurrence at the neighboring Silver Cliff volcano.

Gravity measurements made during a survey of the Silver Cliff volcanic area gave conspicuously low values at stations over the tuff, outlining an 8-mGal low. A review of a low-altitude aeromagnetic survey of the region showed a coinciding magnetic low. A preliminary assessment of the thickness of the tuff unit, from the average density contrast of the involved rocks, indicates about 600 m of tufflike material filling a steep-walled structure in the Precambrian granite.

Minerals of economic interest in the Phosphoria Formation vanidiferous zone, Afton, Wyoming

Electron microprobe studies by G. A. Desborough of unweathered rocks from the vanadium-rich zone in the Phosphoria Formation near Afton, Wyo., revealed that cadmium-rich zinc sulfide, a calcium-molybdenum mineral, and a new titanium-iron-sulphur oxide are present.

Could Belt carbonates contain stratabound lead-zinc ores?

Can the concept of "infiltration" for the formation of stratabound lead-zinc deposits in carbonate rocks be applied to the Precambrian Belt Supergroup? The concept specifies redistribution of lead and zinc during diagenesis and dewatering of sediments where these metals are trapped. Recent geologic mapping by J. E. Harrison in the south-central part of the Wallace 2° sheet, Montana and Idaho, revealed a typical carbonate sequence in the Helena and the upper part of the Wallace Formation consisting of carbonate shelf deposits in the east, slope deposits including large slumps and sedimentary breccia farther southwest, and black shale still farther west. Some of the sedimentary breccia deposits contain small replacement-type fluorite deposits along with trace amounts of copper, lead, and zinc, all of which suggest that the infiltration process may have been active.

Chemical characteristics of hydrothermal alteration at Bingham, Utah

Chemical variations in igneous host rocks of the disseminated copper ore body at Bingham, Utah, are systematically related to the distribution of potassium silicate (biotite ± potassium feldspar) and plagioclase-destructive sericitic (sericite ± kaolinite ± montmorillonite) alteration assemblages, according to W. J. Moore. Potassium silicate alteration is present throughout the copper ore zone. Primary pyroxene and amphibole in equigranular monzonitic rocks from the southeastern half of the ore zone are totally replaced by hydrothermal biotite (average magnesium:magnesium + iron, 0.74). Chemical changes between these rocks and their unaltered equivalents include a slight gain in silica and a moderate loss of Al_2O_3, Fe_2O_3, and CaO; FeO, MgO, Na_2O, and K_2O are generally unchanged, although K_2O is added locally.

Hydrothermal orthoclase is a prominent phase in potassium silicate assemblages from the aplitic porphyry. Bulk compositions of these cryptoperthitic feldspars (Or_{81}) are more potassic than those from unaltered monzonitic rocks (Or_{73}). Determinations of structural state for hydrothermal orthoclase indicate an intermediate degree of aluminum-silicon

ordering. Cooling of the hydrothermal system through the microcline stability field ($T = 4,000°C$) was rapid enough to preclude an inversion to triclinic forms.

Pervasive sericitic alteration is largely confined to host rocks from the northwestern half of the ore zone. This alteration was superimposed upon the potassium silicate assemblage as the hydrothermal system cooled. Rocks from the sericite zone show substantial gains in silica and potassium oxide relative to those from the southeastern half of the ore body; all other major elements show losses.

In monzonitic rocks peripheral to the ore zone, primary pyroxene is commonly rimmed or totally replaced by fibrous (uralitic?) amphibole, and plagioclase crystals are rimmed by orthoclase. These reactions apparently predated the main period of hydrothermal activity and signify a new direction of magmatic evolution leading to the generation of hydrous fluids responsible for successive stages of potassium silicate and sericitic alteration.

Age of volcanism, intrusion, and mineralization in western Utah

The history of volcanism, intrusion, and mineralization in Juab County, western Utah, was outlined by D. A. Lindsey, C. W. Naeser, and D. R. Shawe with the aid of 26 new fission-track age dates. Three distinct ages of volcanic and intrusive rocks were established: (1) volcanic flows and ash-flow tuffs at 38 to 39 m.y., (2) ash-flow tuffs and intrusives at 30 to 32 m.y., and (3) alkali rhyolite flows at 6 to 10 m.y. Fluorspar and beryllium mineralization at Spor Mountain followed extrusion of topaz rhyolite 6 m.y. ago.

Complex igneous and mineralization history at Round Mountain, Nevada

Geologic mapping has clarified the complex history of igneous activity and mineralization in the Round Mountain area of Nevada, according to D. R. Shawe. About 3 km southeast of the town of Round Mountain, a swarm of northeasterly oriented rhyolite dikes of Oligocene age intrudes Cretaceous granite that was cut by veins of quartz tungsten in Late Cretaceous time. Locally intense mineralization that followed intrusion of the rhyolite dikes possibly accounts for metal anomalies (as much as 1,550 ppm Mo and 15,000 ppm Cu) in the vicinity of the dikes. A small biotite diorite stock was emplaced near the northeastern end of the swarm of rhyolite dikes. Tourmaline found in granite and rhyolite near the diorite stock was probably formed during or shortly after the intrusion of the stock.

A volcanic mélange unit, consisting of blocks of large size and compositional variety in an ash-tuff matrix, was deposited in the northern part of the Round Mountain quadrangle and probably was derived from a volcano at Jefferson, 2 km east of the quadrangle. Extensive rhyolitic ash-flow tuffs deposited in early Miocene time probably were derived from the Mount Jefferson volcanic field northeast of the quadrangle. Gold mineralization in the rhyolitic welded tuff at Round Mountain occurred about 1 m.y. after emplacement of the tuff.

Bedded barite in southwestern Nevada

Sedimentary barite deposits of Cambrian and Ordovician age were reported by F. G. Poole in the southern Montezuma Range and southwestern Candelaria Hills of southwestern Nevada. The barite in the Montezuma Range occurs as fine-grained conglomeratic barite interbedded with limestone, silty limestone, and minor chert. The major barite bed is more than 1 m thick and is associated with a silty limestone unit that contains fragments of Lower Cambrian trilobites. In the Candelaria Hills, laminated to very thin bedded dark fine-grained barite in beds as much as several metres thick is intercalated with eugeosynclinal dark mudstone and chert of Ordovician age.

Genesis of turquoise deposits, Shoshone Range, Nevada

Studies by C. T. Wrucke and R. A. Koski showed that turquoise (a copper-bearing phosphate) in the northern Shoshone Range, Nev., occurs mainly along steep faults and thrust zones at the fringes of areas mineralized in gold and base metals. Host rocks are eugeosynclinal siltstone, argillite, and chert of Paleozoic age. Other phosphate minerals in the same environment but not occurring together are crandallite, variscite, and goyazite(?); all are from veins and fillings between fault breccia. Associated minerals include quartz, sericite, and kaolinite. Phosphate for the turquoise could have been derived from sparse but widespread phosphorite in the eugeosynclinal rocks, but whether deposition was by supergene processes, to which it is usually ascribed, or by a low-temperature hydrothermal event associated with hot springs is uncertain. Some gold mineralization in the area is thought to be of hot-spring origin.

Features of Carlin-type gold deposits

Collaborative studies by A. S. Radtke (USGS) and F. W. Dickson (Stanford Univ.) indicated that the

fine-grained, disseminated gold deposits designated as Carlin-type deposits were formed by the action of ascending hot waters that penetrated to the surface or to shallow depths. Conditions during ore deposition ranged from the low temperatures and pressures of a hot-spring environment to epithermal conditions of as much as 225°C and 25 bars. The Carlin-type deposits constitute a previously unrecognized class of ore deposits. They are characterized by the association of gold, pyrite, silica, and organic carbon; exceedingly fine-grained ore minerals; introduced organic compounds; localization of gold in brecciated, carbonaceous, silty carbonate rocks and along high-angle faults that commonly contain altered dikes; fine-grained silicified rocks and jasperoids; and argillized rocks. Visible gold is rare, and base-metal minerals are uncommon. Abnormally large amounts of arsenic, antimony, and mercury occur in the gold ore and in the surrounding country rocks. Thallium occurs in high-arsenic ores. Most deposits contain veinlets of quartz, barite, and calcite. Pyrite occurs as preore syngenetic or diagenetic grains in host rocks and with the ore and also was deposited from the hydrothermal solutions before and possibly during gold deposition.

Ore deposition was in response to drops in temperature and pressure, reaction with wall rocks, and boiling. Boiling took place over a vertical distance of at least 100 m and perhaps as much as 300 m. During the waning stages of hydrothermal activity, the upper level of boiling lowered progressively, and previously mineralized rocks were thus exposed to oxidation. Soluble compounds produced by oxidation migrated downward to react with the hydrothermal solutions and to form late sulfate and carbonate mineral veins.

Stocks and metal deposits in the Santa Catalina Mountains, Arizona

Geologic mapping by S. C. Creasy and T. G. Theodore in the Santa Catalina Mountains, Ariz., suggested that the base-metal deposits are spatially and probably therefore genetically related to the Leatherwood Quartz Diorite and not to the younger, highly sheared Samaniego Quartz Monzonite. The large volumes of pegmatite-aplite probably derived from the Samaniego Quartz Monzonite indicate a water-rich magma. Mineralogic differences within the Samaniego Quartz Monzonite are probably related to compositional differences in the contiguous country rocks. The existence in the heart of the Arizona copper province of an ore-poor quartz monzonite derived from a hot, water-rich magma is noteworthy. The economic significance, if any, of the intense deformation that transformed much of the Samaniego Quartz Monzonite into a gneiss is not known.

Fluid inclusion studies on ore from Ray, Arizona

Preliminary study by T .G. Theodore of fluid inclusions in quartz-bearing ore collected by N. G. Banks from the porphyry copper deposit at Ray, Ariz., yielded results different from those typical of most such deposits. Most significantly, at Ray there is a marked paucity of the gas-rich varieties and polyphase types of inclusions common in many other porphyry copper deposits. Fluid inclusions of both primary-pseudosecondary and definitely secondary origins at Ray are unsaturated at room temperature with respect to sodium chloride (<26 weight percent sodium chloride equivalent), and they are composed primarily of liquid plus a small vapor bubble. All inclusions yield relatively low filling temperatures, with a range of 195° to 350°C and an approximate mean of 270°C, irrespective of host-rock or sulfide-vein mineralogy. Paragenetically late galena-sphalerite-pyrite-quartz veins yielded some of the highest filling temperatures; this relation is somewhat enigmatic because thermal declines with time are ascribed to most such sulfide-silicate systems. Actual trapping temperatures, however, may have been much higher than these temperatures because of potentially large corrections to filling temperatures required by the uncertain pressure environment during metallization.

Laramide plutonism and mineralization west of Safford, Arizona

Recent mapping by P. M. Blacet in the Santa Teresa and Turnbull Mountains, northwest of Safford, Ariz., demonstrated that the Santa Teresa Granite and the Goodwin Canyon Quartz Monzonite are mutually gradational facies of an early Tertiary(?) batholith exposed over an area of approximately 330 km^2. This unusually large epizonal pluton, probably the largest mass of Laramide granitic rock exposed in Arizona, intrudes rock at least as young as the Pinkard Formation of Upper Cretaceous age and has an apparent lead-alpha age of 60 ± 10 m.y. (Simons, 1964).

Disseminated pyrite and chalcopyrite occur in altered coarse-grained granite at several localities in the south-central part of the batholith. Small replacement deposits of magnetite and the manganese pyroxene johannsenite were discovered in skarn de-

veloped from lower Paleozoic limestone and shale in a roof remnant in the central part of the batholith.

South of the batholith, in the Eagle Pass area, a swarm of Laramide(?) porphyry dikes is associated with widespread alteration and mineralization. Exotic secondary copper minerals apparently have leaked through a Miocene thrust plate that covers the western part of the dike swarm 18 km southeast of Klondyke. The dike swarm is interpreted as part of a major Laramide tectometallogenic zone trending approximately N. 70° E. through San Manuel, Safford, and Morenci. This belt occupies a central position in the famed copper quadrilateral and is the locus of three of the largest porphyry copper districts in the United States.

GEOLOGIC STUDIES IN POTENTIALLY MINERALIZED AREAS

AREAL MINERAL APPRAISAL

Black sands in the Lake Superior beaches

A geochemical survey in the Michigan part of the Sault Ste. Marie 2° quadrangle to find areas that may have potential for economic metallic and nonmetallic deposits was conducted by J. W. Whitlow, J. F. Windolph, T. W. Broadhead, and D. L. Pearson. Dark-gray to black sands in a bed or beds up to 30 cm thick in the beaches along the south shore of Lake Superior were found to contain as much as 11 percent TiO_2, 0.2 percent V, and greater than 20 percent Fe. No other areas with potential for ores of metals were found.

Geochemical sampling indicates belt of copper mineralization in Calamine quadrangle, Lafayette County, Wisconsin

Chemical and semiquantitative spectrographic analyses of soil and stream sediment samples collected by W. S. West showed a belt of copper mineralization at least 12.9 km long extending north-south across the Calamine quadrangle, Wisconsin. The mineralized belt may extend northward to the copper occurrence at Mineral Point and southward to the Apple River quadrangle.

The north-south trend of this copper mineralization contrasts with the general east-west trends of the lead and zinc mineralization in the Upper Mississippi Valley district.

Copper potential in the eastern half of the Tucson 2° quadrangle, Arizona

A map showing the relative potential for the occurrence of copper deposits in an area of more than 10,000 km² extending from the Tucson Mountains to Sulfur Springs Valley near Willcox, Ariz., was prepared by the U.S. Geological Survey (1974) for use by land-use planners, governmental agencies, conservation groups, and companies or individuals interested in the mineral industry, according to P. M. Blacet. The map outlines areas of relatively high, intermediate, and low potential for hosting copper deposits and, to a lesser extent, indicates favorable areas in which to explore for associated zinc, lead, gold, and silver deposits. The zones of relative mineral potential are plotted on a simplified geologic map along with the locations of known copper deposits and minor copper occurrences. The map is the second of a series planned for part of southern Arizona to classify land according to its relative mineral potential.

Mineralization in Hillsboro area, New Mexico

Geologic maps of the Hillsboro-San Lorenzo 15-min quadrangles, New Mexico, were completed in 1974, and three selected mineralized areas were mapped in detail. D. C. Hedlund reported that three areas of detailed resource mapping were the Copper Flat copper porphyry in the Animas Hills district (1:6,000 and 1:24,000), the Kingston silver district (1:6,000), and base-metal deposits in the Swartz (Carpenter) mining district (1:24,000).

The small quartz monzonite body of Copper Flat is a relatively nonweathered subvolcanic stock that has intruded andesite and andesite breccias of Late Cretaceous age. The stock has an area of about 1.0 km² and, on the basis of limited drill-hole data, appears to have steeply expanding contacts with the surrounding andesite. Biotite from the quartz monzonite has been dated by the K-Ar method as 73.4±2.5 m.y. (R. F. Marvin, H. H. Mehnert, and V. M. Merritt, unpub. data, 1974). The copper mineralization is confined mainly to the altered central part of the intrusion where numerous fracture fillings and disseminations of pyrite, chalcopyrite, and bornite are localized in the sericitized quartz monzonite.

In the Kingston district, fissure veins that contain silver-bearing base metals are localized along major faults that strike N. 10°–20° W. The silver content of the unoxidized ores is as much as 790 ppm and averages about 440 ppm (six analyses). The chief silver minerals are cerargyrite, argentite, and polybasite; the galena is argentiferous and contains as much as 1,300 ppm Ag. Other ore minerals include sphalerite, pyrite, chalcopyrite, and alaban-

dite. The sphalerite contains exsolution-type blebs of chalcopyrite, and electron microprobe analyses of the pyrite-associated sphalerite indicate 1.91 to 2.40 mole percent FeS. This low FeS content suggests relatively low depositional temperatures.

Sphalerite-rich base-metal deposits of middle Tertiary age (about 33 m.y.) are localized along strong faults that strike N. 10°–20° W. through the Swartz mining district. Both fissure veins and bedding replacement bodies are also closely associated with a zone of thermal metamorphism that extends for at least 9.7 km along the strike of faulted Paleozoic carbonate rocks. The contact metamorphic assemblage of diopside, epidote, tremolite, wollastonite, grossular garnet, phlogopite, fluorite, helvite, and magnetite suggests temperatures of about 500°–650°C under very small load pressures. This thermal metamorphism preceded the mineralization, but both events are attributed to the intrusions of rhyolite stocks, plugs, and dikes into the Paleozoic strata.

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 of lands being considered for inclusion in the National Wilderness Preservation System. To aid in evaluating suitability for wilderness inclusion, the USGS and the U.S. Bureau of Mines are making mineral-resource appraisal surveys of primitive and other areas of the national forests, as well as of wilderness areas established by the Act.

PRIMITIVE AREAS

Mineral surveys have been completed on all 34 primitive areas, totaling about 2.9 million ha. Reports on 31 of the areas have been published as USGS Bulletins, and reports on the remaining three were open filed during 1973; they will be printed during 1975 and 1976.

WILDERNESS AREAS

Mineral surveys have been completed on 15 of the 54 wilderness areas that were established before or by the Wilderness Act of 1964. A report on the Scapegoat Wilderness, Mont., was published in 1974, and a report on the San Pedro Parks Wilderness, N. Mex., was published in 1975. Field work has been completed and the reports are in preparation in five wilderness areas, and field work is underway in three areas.

Maroon Bells-Snowmass

Geologic mapping in the Maroon Bells-Snowmass Wilderness Area of Colorado by V. L. Freeman and Bruce Bryant demonstrated Oligocene faulting along Avalanche Creek in the Redstone quadrangle. The fault that extends from the intrusions associated with Mount Sopris on the north to the Snowmass pluton at the south trends north-northwest, is probably nearly vertical, and has a displacement of about 100 m, the southwestern side being relatively unlifted. Some right-lateral movement is possible. Movement along the fault occurred prior to or contemporaneously with intrusion of granodiorite of Oligocene age.

STUDY AREAS

Mineral surveys of 77 of the 295 areas being studied by the Forest Service for the Wilderness System have been completed. Investigations of 13 of the completed study areas are included in reports on primitive and wilderness areas. An Eastern Wilderness Act signed in 1975 established 17 study areas to be studied in 5 yr. Studies of three areas are complete, and the study of one area is in progress.

Open-file reports have been released for the Sawtooth Recreation Area, Idaho; the Trinity Alps addition, Calif.; the Du Noir area, Wyo.; and the Cougar Lakes-Mount Aix and Alpine Lakes additions, Wash. Results from some of the areas are given below.

Boulder Pioneer study area, Idaho

Dominantly allochthonous rocks underlie about 2,500 km^2 in the Pioneer Mountains, Idaho. J. H. Dover, S. W. Hobbs, W. E. Hall, F. S. Simons, C. M. Tschanz, and R. J. Ross, Jr., recognized at least six major thrust plates of Paleozoic sedimentary rocks, each with its own distinctive stratigraphic sequence and (or) structural-metamorphic style. Parautochthonous(?) Precambrian gneiss and lower to middle Paleozoic shelf sediments are exposed in three structural windows. Evidence is accumulating that major structures of Antler (mainly Mississippian) age have been moved into the Pioneer Mountain area upon large thrust faults of Mesozoic age. Cumulative crustal shortening of at least some tens of kilometres, and perhaps as much as 150 km, is suggested by reconstruction of early Paleozoic paleofa-

cies combined with intense deformation over an extensive area within the allochthons.

Eastern part of Sawtooth National Recreation Area, Idaho

The eastern part of the Sawtooth National Recreation Area covers about 2,100 km^2 in central Idaho. The mineral-resource study was done by C. M. Tschanz, T. H. Kiilsgaard, and D. A. Seeland (USGS) and R. M. Van Noy, James Ridenour, N. T. Zilka, F. E. Federspiel, R. K. Evans, E. T. Tuchek, and A. B. McMahon (U.S. Bureau of Mines) (1974).

The geology of the area is complex and consists of deformed and metamorphosed sedimentary rocks that have been intruded by granitic rocks and overlain by volcanics, glacial deposits and alluvial deposits. The study area is near the southeastern margin of the composite Idaho batholith, which underlies the northwestern third of the area and encloses the smaller, younger Sawtooth batholith immediately to the west. The Idaho batholith intrudes metasedimentary rocks of probable Precambrian age in the northwestern part of the area. Folded and faulted sedimentary rocks that range in age from Ordovician to Permian form an arcuate belt trending northerly through the center of the area and are intruded by the Idaho batholith, the White Cloud, Horton Peak, and Boulder Mountains stocks, and by several smaller stocks. In most of the eastern third of the area, the sedimentary rocks and intrusives of the composite Idaho batholith are overlain by the Challis Volcanics and intruded by hypabyssal porphyries that are related to the volcanics.

The area is in one of the most highly mineralized and potentially productive regions in Idaho and contains large undeveloped mineral resources. The mineral evaluation of the area is based on the past mineral production, the results of recent exploration by claim owners, and the results of this study. The value of past mineral production from the area, at prices prevailing at the time of production, is estimated from incomplete records to be at least $5 million. The total estimated production from mining districts within 16 km of the study area exceeds $50 million.

The potential value of known mineral resources in the area exceeds the value of the total past production by a factor of between 70 and 100. The most important deposits are large marginal resources of molybdenum near Boulder Creek and large reserves of zinc recently determined in the Hoodo Mine; cadmium occurs with the zinc and adds appreciably to the value of the large reserves. Many tungsten, molybdenum, and uranium deposits have been discovered or developed since 1952 in accessible areas within or near the study area. The principal resources, in estimated order of decreasing potential value, are molybdenum, zinc, silver, gold, lead, fluorite, antimony, cadmium, and graphite. Niobium, uranium, thorium, rare earths, and titanium are potential coproducts of placer gold mining. Small amounts of tin, tungsten, bismuth, mercury, selenium, and tellurium also occur in the area.

Target areas that may contain additional mineral resources were indicated by the results of geochemical and geophysical surveys. The most promising are zinc anomalies at Mill Creek and at several streams in the Slate Creek drainage, where zinc-cadmium deposits similar to the deposit at the Hoodoo Mine are inferred in the Mississippian and Devonian(?) rocks, and zinc and silver-lead anomalies at Grand Prize Gulch. The results of electromagnetic surveys indicate conductors that may represent mineralized zones in these areas, as well as in the Buckskin and Valley Creek mine areas near the northern boundary, where gold-silver-bearing veins are present.

Some silver-lead-bearing veins in the area contain small amounts of tin in the form of cassiterite and stannite. The present economic value of the tin resources is uncertain; however, these deposits are unique in the United States, and they are a possible future source of this domestically rare, important metal.

Cougar Lakes-Mount Aix study area, Washington

The Cougar Lakes-Mount Aix study area covers approximately 673 km^2, chiefly along the eastern side of the crest of the Cascade Range on the east of Mount Rainier National Park in Yakima and Lewis Counties, Wash. The mineral-resource study was done by G. C. Simmons (USGS) and R. M. Van Noy and N. T. Zilka (U.S. Bureau of Mines).

Most of the study area is underlain by volcanic and intrusive rocks; perhaps 10 percent are underlain by older sedimentary rocks. These rocks are intruded by younger granitic rocks followed by rhyodacite. Most of the mineralization is in pyritized and altered zones along the margins of the younger intrusives. Following intrusion and mineralization, the area was alternately eroded and partly covered during three periods of volcanism. The area contains small, uneconomic deposits of copper, mercury, zinc, and manganese, and the only potential for a large metalliferous body is near Mesatchee Creek, in an area that is presently being

explored for copper. A small amount of mercury was produced from the Red Spur mine, and small shipments of manganese ore reportedly have been made from the Fig property, both in the southeastern part of the area. Although the exposed mercury occurrences are submarginal, the potential for discovering other small deposits of this metal exists in the area. A potential zinc resource exists in the area near Little Twin Sister Lake. In the Miners Ridge district, outside the study area, copper, silver, and tungsten were mined from northwesterly striking shear zones that extend toward the crest of Miners Ridge and possibly into the study area.

Data on the geology and analyses of spring water indicate that part of the area may have a potential for geothermal energy.

Alpine Lakes study area and additions, Washington

The Alpine Lakes study area and additions lie along the crest of the central Cascade Range in Chelan, King, and Kittitas Counties, Wash. The mineral-resource evaluation of the study area and additions, consisting of 1,551 km^2, was done by J. L. Gualtieri and G. C. Simmons (USGS) and H. K. Thurber, M. S. Miller, A. B. McMahan, and F. E. Federspiel (U.S. Bureau of Mines).

The area is divided into an eastern block and a western block by the northwest-trending anastomosing Deception Creek Fault; the eastern block is characterized by pre-Cretaceous metamorphic rocks of granitic, mafic, and ultramafic composition that are cut by thrust faults and minor high-angle faults. The western block is characterized by late Mesozoic and Tertiary sedimentary, volcanic, and granitic rocks with only minor amounts of pre-Cretaceous rocks. Most of the mineralization is in highly altered shear zones and veins near the Mount Stuart batholith of Cretaceous age and the Snoqualmie batholith of late Miocene age.

The mineral evaluation is based on reconnaissance geologic mapping, geochemical sampling, an aeromagnetic survey, and examination of mines, prospects, and claims. The drainage basins of Gold Creek, Mineral Creek, Van Epps Creek, Lemah Creek, and the Snoqualmie River have a potential for low-grade copper resources in mineralized breccia zones. Granitic rocks in the Gold Creek Valley area may contain disseminated copper sulfide minerals at depth. Several vein-type mineral deposits are in the area; some of them contain moderately high values of copper and silver, and some contain minor amounts of gold.

A poorly defined zone of disseminated copper deposits appears to extend from the area of the Snoqualmie River southward through the Gold Creek area to the Mineral Creek area.

The Porter-Crawford Creek area has a potential as a large low-grade copper resource. The Porter-Hemlock-Condor mineralized zones are presently being explored, and they may contain large commercial deposits of copper. The Three Brothers zone may contain as much as 1.8 million tonnes of mineralized rock averaging 0.8 percent Cu. The Red Face mineralized zone of low-grade disseminated copper may be a potential resource.

Anomalous stream sediment and rock samples from Big Creek, Cougar Creek, Lennox Creek, the Miller River, and Gouging Lake areas suggest the presence of undiscovered vein deposits of silver, copper, and molbydenum. The Cleopatra mine is estimated to contain over 90,000 tonnes of mineralized rock grades ranging from 187.5 to 531.3 mg of silver per kilogram. Detectable amounts of gold were found in many places in the study area, but only the Lennox mine in the Lennox Creek drainage has produced gold ore

MINERAL COMMODITY APPRAISAL

Summary of the principal findings of Professional Paper 820

The encyclopedic nature of "United States Mineral Resources" (USGS Professional Paper 820) seems to have inhibited its widespread use by people other than professional geologists. A summary of the principal findings and conclusions of Professional Paper 820 is presented in Circular 698 (W. D. Pratt and D. A. Brobst, 1974), which gives special regard to the resources of 27 mineral commodities of major importance to our industrial civilization (on the basis of dollar value) and to the problems involved in using the resources of the 10 most important nonferrous metals, the 11 principal ferrous metals, and the 6 principal fossil and nuclear fuels.

New appraisal of alunite resources

A reappraisal of alunite resources in the Western States by R. B. Hall was stimulated by revived interest in nonbauxite sources of aluminum. Deposits at Marysvale, Utah, well studied during both World Wars as a potential source of aluminum and potash, are insufficient to serve as a long-term resource; however, recent exploration by a private consortium has found large reserves in Tertiary volcanic terrane in Beaver County, Utah, that place

alunite in a more favorable light as a possible domestic source of aluminum and a partial alternative to imported bauxite. Potassium sulfate fertilizer and sulfuric acid are potential byproducts, the recovery of which is essential to the economic utilization of alunite ore. Large tonnages of alunite-bearing rock exist in solfatarically altered volcanic rocks of Tertiary age in southern Nevada, southern Arizona, and the San Juan Mountains of southwestern Colorado, but the tenor in these deposits is not known. Alunite-processing technology seems well established, although its economic feasibility is not yet proven. Pilot plant testing of Utah ore by a private consortium has been in progress for several years.

Chemical differences between types of ultramafic bodies

M. L. Bird, in a microprobe study of ultramafic rocks, found that the differences in composition of chromite, olivine, and pyroxene, the respective trends in compositional variation, and the major-element distribution between the respective minerals serve to distinguish the alpine-, stratiform-, and concentric-type ultramafic bodies. The platinum-containing concentric-type bodies can be distinguished from the alpine type, and, within the alpine type, those bodies that may contain metallurgical-grade chromite can be distinguished from those containing refractory-grade chromite. Stratiform bodies that may contain sulfides are distinguished from the other types.

Fluorspar districts controlled by major tensional faults

Review of the principal fluorspar districts of the United States by R. E. Van Alstine showed that they are associated with continental rifts and other major zones of tensional faulting. In Illinois and Kentucky, the deposits are along and near the junction of the New Madrid and Shawneetown-Rough Creek fault zones. In the Rocky Mountains, they are along and near the Rio Grande rift zone and its northward projection to the Canadian border. In Nevada and Utah, the deposits are in tensional faults of the Basin and Range province.

The western deposits commonly are located in high-angle normal faults, are low-temperature and low-pressure types, have silicified wall rocks, and are middle to late Tertiary in age. Locally, the deposits or their controlling structures are associated with Tertiary silicic or alkalic intrusive rocks, flows or hypabyssal bodies of basalt, silicic or alkalic rhyolitic volcanic rocks, calderas, hot springs, and gravity-low areas. The high heat flow in and near the tensional structures suggests that magma and volatiles were transferred upward; volatile fluorine from the mantle or lower crust probably was the ultimate source for the near-surface fluorspar deposits.

Commercial fluorspar deposits are associated with zones of tensional faulting elsewhere in the world: for example, Mexico, the Rocky Mountain trench of Canada, the rift zones of Africa, and the Rhone and Rhine grabens of Spain, France, and Germany.

Tools for prospecting for vermiculite

Vermiculite deposits are associated with ultramafic rocks and are formed in the zone of weathering. About one-third of our production comes from South Carolina, where weathering is deep, the rocks generally are not well exposed, and the ultramafic bodies have areas of only a few hectares. The magnetic susceptibility of ultramafic rocks is commonly greater than that of granitic rocks, so that A. L. Bush suggested that aeromagnetic survey might pinpoint anomalies caused by the ultramafic bodies. A survey of about 650 km^2 in Laurens County, S.C., revealed about 20 anomalies, but field examination showed that susceptibility contrasts were too low to distinguish between ultramafic and granitic rocks associated with the vermiculite deposits, and the amonalies could not be used to identify potential ultramafic host rocks.

Western termination of Negaunee Iron-Formation

The Negaunee Iron-Formation (Precambrian X) is the principal iron-producing unit of the Marquette Iron Range in northern Michigan. In the past, it has yielded ore as far west as the town of Michigamme. Westward from that point, the unit thins rapidly from about 150 m just west of Michigamme to 45 m or less within about 1 km along strike, according to W. F. Cannon. Still farther west, the Negaunee is not exposed but has been traced by magnetic surveys for about 8 km. Near the town of Three Lakes, about 5 km west of Michigamme, several diamond-drill holes penetrated about 15 to 30 m of iron-formation, and a magnetic anomaly of about 10,000 gammas is caused by the iron-formation. The anomaly is about 5,000 gammas 1.5 km farther west, and it disappears completely within another 1.5 km.

Environmental impact of mining peat in Maine

C. C. Cameron (1975) determined from studies of five physiographic forms of peat deposits in Wash-

ington and southern Aroostook Counties, Maine, that exploitation during the past 75 yr has made little impact on the heath-covered dome-shaped bogs that are best suited for the production of commercial-quality sphagnum moss peat. This exploitation has so little effect because the peat was removed from the parts of the domes lying above the regional water table and because remaining remnants of heath flora regenerated new peat. So long as a regional ground-water table is little changed by keeping drainage ditches at minimum depth and some patches of heath flora are left undisturbed, peat mining in sphagnum dome-shaped bogs, such as those that occur in Maine, may not cause permanent change. However, recent usage of modern machinery for rapid clearing of the heath surface and for ditching makes preliminary studies of the regional and perched water-table positions and relationships, the physiographic form of the deposit, and its biology important in order to prevent unnecessary damage to the environment.

Economic geology of phosphate deposits

Until recent years, only tonnage, P_2O_5 content, and geographic location were enough to characterize, economically, most phosphate deposits. Because most phosphate rock today is used to make sophisticated chemical fertilizers (for example, triplesuperphosphate, polyphosphate, diammonium phosphate, and phosphoric acid), a great many other chemical analyses must be made to determine the economics and potential uses of phosphate rock from any deposit. Lime (CaO) in amounts greater than needed in the apatite mineral is deleterious in acidulation because of greater use of sulfuric acid and is deleterious in thermal phosphate manufacturing because of the need to add silica to turn all of the CaO into calcium silicate flux. The ratio of $CaO{:}P_2O_5$ in marine apatites is about 1.5; anything greater than 1.5 indicates that some calcite is probably present. Iron and alumina, as Fe_2O_3 and Al_2O_3, are both deleterious in making phosphoric acid or thermal phosphates because of the formation of insoluble aluminum and iron phosphates and the formation of ferrophosphate. The total content of aluminum and iron oxides in phosphate rock should be less than about 3.5 percent, and the lower the better. Magnesium oxide (MgO) in amounts greater than 0.2 percent is bad for the manufacture of phosphoric acid. Chlorine in amounts greater than about 0.15 percent causes serious corrosion problems in the manufacture of phosphoric acid. Organic material should be less than 0.5 percent because of problems with foaming when phosphate rock is acidulated with sulfuric acid. Pyrite is deleterious because of formation of hydrogen sulfide (H_2S) on acidulation. If any of these elements are present in amounts that are too large, processing must be changed, or the deposit may be uneconomic.

Certain minor elements either are being recovered or could be recovered in processing phosphate rock. For example, fluorine is being recovered as a byproduct; uranium was recovered from Florida phosphate rock, and plants are currently being built to recover uranium. Vanadium has been recovered as a byproduct in thermal processing of phosphate rock in the western field, and the rare earths are present in amounts that may be recoverable. It is, therefore, necessary to analyze phosphate rock for these elements to determine if they can be recovered in processing.

The elements B, Cu, Fe, Mn, Mo, and Zn are required in very small amounts for optimum plant growth. These so-called micronutrients are present in most marine phosphorites in minor amounts but are largely removed in chemical processing. They must then be added to the final products for best plant growth.

The carbon dioxide (CO_2) content of the carbonate fluorapatite, the apatite mineral of the marine phosphorites, varies widely. The apatite mineral is more soluble in acid ground water with increasing amounts of CO_2, and, in addition, the high-CO_2 apatites are easier to acidulate than the low-CO_2 apatites. The amounts of CO_2 present in the apatite, then, are a measure of how successful the particular rock may be in direct application to soil, and the CO_2 content may determine methods of chemical treatment.

Thus, economic appraisal of a phosphate deposit requires, today, very sophisticated chemical analyses and considerable study by the geologist.

Lithium demand may soon exceed supply

The lightest of all metals, lithium, is currently in short supply for conventional uses such as ceramics, multipurpose greases, aluminum reduction, and absorption of carbon dioxide. Meanwhile, research on rechargeable lithium batteries for electric vehicles and off-peak power storage suggests that a vastly increased demand for lithium may soon develop. Overshadowing these uses is the potential future requirement for lithium in thermonuclear power plants, where it serves as a source of the fuel element tritium and also assists in the absorption of thermal neutrons.

Although data on lithium production and consumption are regarded as privileged information by the industry, recent estimates suggest a 10 percent/yr growth since 1968, when the production was estimated at about 2.6×10^6 kg, or about 4.5×10^6 kg in 1974. If 10 percent of the automobiles produced in the United States were to convert to lithium-battery power, the demand for lithium could increase tenfold. The requirement for stationary lithium batteries for off-peak power storage has not been determined. Although the requirement for thermonuclear powerplants varies with design, one typical design calls for 930 kg of lithium per million watts of electrical power (MWe). The anticipated 500,000-MWe thermonuclear power capacity by the year 2020 would require 460×10^6 kg of lithium metal. Thus, we are on the threshold of a tremendous potential increase in the demand for lithium.

Our lithium resources are not as great as recent published estimates have suggested. The Clayton Valley brinefield near Silver Peak, Nev., is currently estimated to contain a reserve of about 45×10^6 kg of lithium, or about one-hundredth of the amount suggested in preliminary estimates. Until new resources can be developed, the anticipated discrepancy between supply and demand will have to be made up by increasing the rate of production of spodumene from the Kings Mountain pegmatites, which have total resources of about 500×10^6 kg.

Lithium in the Rocky Mountain region

Reconnaissance by E. B. Tourtelot throughout the Rocky Mountain States suggested several areas of abnormally high lithium content. The preliminary data point to a relationship between lithium anomalies and volcanic activity—for example, lithium anomalies occur in the sedimentary rocks in the moats of calderas. Anomalous amounts of lithium also have been found in sedimentary rocks that have been hydrothermally altered and in clays associated with hydrothermal veins. Lithium apparently tends to stay in solution and may travel further than other ore metals.

The relationship between lithium, borates, and volcanic activity

Anomalous concentrations of lithium occur throughout a large part of the Western United States. Some of these anomalies are associated with nonmarine evaporite deposits in both modern and ancient closed basins, according to R. G. Bohannon. The high ratio of lithium to sodium in most of these deposits precludes any possibility of a simple origin by concentration of seawater or by solution and reconcentration of marine evaporites. The common association of lithium with borates suggests the possibility of a common origin. One possibility is that both lithium and boron are derived from late Tertiary volcanic activity and the associated geothermal waters in areas such as the Long Valley caldera.

Subsurface brines may be a source for lithium

Lithium is one of the most soluble alkali metals; it tends to move in aqueous solution and remain in a natural brine solution even beyond the precipitation of potassium salts. Evaporation of seawater to the stage at which potassium salts are precipitated results in approximately 30 mg/l of lithium still in solution, losses being caused by fluid inclusion in precipitated salt. Collin (1974), in an article on potential marketable minerals in oilfield waters, listed seven localities with saline brines equal to or exceeding this lithium concentration. A limited review of the literature by R. K. Glanzman indicated that a lithium concentration of 300 mg/l occurs in several subsurface brines in the United States.

Cycling of platinum metals in the Stillwater Complex, Montana

N. J Page reported that platinum, palladium, and rhodium analyses done by Joseph Haffty for basal zone rocks of the Stillwater Complex, Mont., show (1) a distribution of values that cycle or oscillate in a manner similar to those of the rock types and (2) chemical and physical properties of the silicate and oxide minerals. This correlation of cyclic patterns suggests that the chemical and physical parameters, such as magma composition, temperature, and partial pressure of oxygen, that control the accumulation of the rocks also exert some control over the concentration of the platinum metals. Analogous patterns of cycling for platinum metals were found within an olivine cumulate unit of the ultramafic zone in the complex.

New polymetallic tin province in central Idaho

A new province of polymetallic tin-bearing sulfide veins was found during the evaluation of the mineral resources of the Sawtooth National Recreation Area by the USGS and the U.S. Bureau of Mines (C. M. Tschanz and others, 1974). Narrow tin-bearing veins in 35 silver-lead prospects form an arcuate north-trending belt about 46.7 km long in Carboniferous sedimentary rocks. The principal metals in these veins are Ag, Pb, Zn, Sb, Sn, and smaller amounts of Cu and Au. Ten veins contain at least 0.5 percent Sn, and three locally contain 2 to 6 percent. Tin contents greater than 0.7 percent are confined to two

areas 19.3 km apart. In the northern area, the predominant valuable minerals are lead sulfantimonides, sphalerite, and stannite and(or) cassiterite. In the southern area (Galena district), the predominant mineral is galena, but, locally, as many as 25 metallic minerals are present, including many tin and silver minerals.

Tin minerals studied by B. F. Leonard in one sample containing 2.2 percent Sn from the Galena district include four minerals of the stannite family, cassiterite, tellurium canfieldite, minute inclusions of several unidentified sulfidic tin minerals in galena, and the oxidation product termed varlamoffite. The stannite family includes an unknown zincian stannitelike mineral, kesterite (zinc analog of stannite), "isostannite"(?), and "brown stannite"(?). Microprobe analyses by G. A. Desborough indicated 7 percent Zn in the unknown mineral and 15 percent Te in the canfieldite. This occurrence of tellurium canfieldite, which is the principal silver mineral in the specimens studied, is the third to be reported.

The tin-bearing silver-base-metal veins are unusual in the United States but resemble some productive sulfidic tin deposits in Bolivia, Siberia, and Canada. The only known comparable domestic deposits are those sampled by A. V. Heyl in the Delno district, Elko County, Nev., but somewhat similar deposits might be found in other western silver-lead districts. Although the present economic value of tin is doubtful, the Idaho tin province is one of few potential domestic sources of tin that has not been prospected thoroughly.

Titanium resources

Four investigators (Norman Herz, 1975; M. C. Blake, Jr., and B. A. Morgan, 1975; E. R. Force, 1975) contributed reports discussing new types of titanium resources or new viewpoints on old types. Topics include: (1) partitioning of titanium between silicates and oxides; (2) the relation between titanium placer deposits and the metamorphic grade of source terranes; (3) rutile in blueschists; (4) titanium deposits in anorthosite; (5) titanium deposits in alkalic rocks; and (6) titanium minerals in deposits of other commodities. Alkalic rocks and blueschists containing titanium minerals are new and potentially major types of resources.

Ilmenite in Pleistocene beach sands of Virginia

E. R. Force has made a map at 1:250,000 of heavy mineral resources in Pleistocene beach sands of southeastern Virginia based on new mapping and on existing mapping by R. Q. Oaks and N. K. Coch (formerly of Yale Univ.) and by G. H. Johnson (College of William and Mary). Fifty channel samples through the sand bodies were evaluated for resources of titanium. Bodies of sand up to 12 m in average thickness contain as much as 1 percent ilmenite and thus constitute marginal TiO_2 resources.

Zeolites in Pliocene lacustrine rocks, Durkee basin, Baker County, Oregon

Zeolites, potassium feldspar, silica minerals, and clay minerals of diagenetic origin occur in altered silicic tuffs of lacustrine deposit in the Durkee basin, Oreg. According to R. A. Sheppard and A. J. Gude III (1975), the zeolites are chiefly chabazite, clinoptilolite, and erionite, although minor amounts of analcime, phillipsite, and mordenite have been identified. The zeolitic tuffs are less than 1 cm to about 2 m thick, but most are more than 15 cm thick. Some of the relatively thick chabazite- and erionite-rich tuffs have economical potential. Zeolitic and feldspathic tuffs are restricted to the central part of the ancient lake basin and to the lower half of the stratigraphic section. Tuffaceous rocks in the marginal part of the basin contain fresh vitric material that is locally altered to montmorillonite. Tuffaceous beds in the upper half of the section consist mainly of fresh glass and are interbedded with thick diatomite beds. Except for analcime, the zeolites are locally associated with relict glass. Neither analcime nor potassium feldspar is associated with relict glass. Textural evidence indicates that analcime formed from chabazite, clinoptilolite, erionite, and phillipsite; potassium feldspar formed from analcime and clinoptilolite. The distribution of zeolites and other diagenetic silicate minerals in the tuffs is due to the original chemical variations of the lake water. Probably the water was relatively fresh in the marginal part of the basin but increased in salinity and alkalinity basinward.

Potential for metals in glauconitic sandstones

P. L. Weis and Helmuth Wedow, Jr., reported that certain marine sandstones, chiefly those with a strong glauconitic component, in the Eastern United States have a potential for stratabound base-metal deposits. Of particular import for copper are the Lower Cambrian Rome Formation and its stratigraphic equivalents in the Appalachian region from Alabama to eastern Canada and the Upper Cambrian Franconia Formation in Wisconsin and Minnesota. Anomalous zinc appears to be widespread in the Devonian Huntersville, Oriskany, and Helderberg Formations in Pennsylvania, West Virginia,

and Virginia. In addition, gold has been reported to be associated with greensands of the Franconia as well as with those of the Mississippian Floyd Knob Formation in Kentucky and in the Tertiary of eastern Texas. The glauconite is deposited locally with siderite in a mildly reducing iron-formation environment. It is postulated that this environment is also especially favorable for the precipitation of other metals, chiefly by entrapment of metals ions in the rather open glauconite lattice. Introduction of sulfur into this system from decaying organic matter or by bacterial reduction of sulfate would precipitate the metals as fine-grained interstitial sulfides. Further concentration would result after early remobilization and later reprecipitation in the pores of early structural or stratigraphic traps or by later movement into well-developed fractures and pores formed during younger orogenic disturbances.

OFFICE OF MINERALS EXPLORATION

MINERALS DISCOVERY LOAN PROGRAM

Financial assistance on a participating basis to private industry to explore deposits of certain minerals is offered by the USGS's Office of Minerals Exploration (OME) under Public Law 85–701, approved August 21, 1958. Individuals or private firms must meet the eligibility requirements of the program, and approved project proposals must offer reasonable geologic probabilities that significant discoveries of ore may be made by the exploration work. Contracts for the exploration work are prepared for approved applications. Repayment of Government funds expended on contracts and payment of simple interest are made through a royalty of 5 percent on the value of minerals produced from properties during the period of the exploration work. If the Government issues a certificate of possible production based on favorable results of completed contract work, the obligation for royalty payments continues for not less than 10 yr or until the principal and interest are repaid in full, whichever occurs first. No repayment is required if there is no production, and the Government is not obligated to purchase any minerals produced.

At present, the following 27 minerals or metals are eligible for Government participation in 50 percent of the allowable costs of exploration:

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

The following nine minerals or metals are eligible for Government financial assistance in 75 percent of of the allowable costs of explorations:

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

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

Activity on the OME program in calendar year 1974 and totals for the program through December 31, 1974, were as follows:

	Calendar year 1974	*Program totals, 1958 through 1974*
Applications:		
In process of review Jan. 1, 1974	10	
Received	5	[1] 945
Denied	1	387
Withdrawn or inactive	13	350
Approved	1	208
In process of review Dec. 31, 1974	0	
Contracts:		
Executed	1	208
Total value	[2] $157,120	[3] $13,281,354
Government share	[2] $75,770	[3] $7,644,277
Disbursements	$138,313	[3] $4,775,897
Repaid to Government through royalties on production	$7,996	$412,933
Estimated recoverable value of reserves at present metal prices	$4 million	$167 million

[1] Total estimated cost of proposed exploration, $90 million.
[2] Includes value added to an existing contract by two amendments.
[3] Revised total.

Silver and gold exploration projects accounted for about 66 percent of the total value of contracts conducted on the program from 1958 through 1974:

Commodity	Number of contracts	Total value of contracts	Percentage of total value
Silver	74	$5,505,000	41
Gold	64	3,145,000	24
Mercury	17	1,162,000	9
Copper	14	858,000	6
Lead-zinc	7	682,000	5
Lead-zinc-copper	11	488,000	4
Molybdenum	3	384,000	3
Iron	3	200,000	1
Beryllium	3	127,000	1
All others (cobalt, fluorspar, mica, nickel, platinum, uranium)	12	[1] 730,000	6
Total (15 commodities)	208	$13,281,000	100

[1] Revised.

MINERAL-RESOURCE EXPLORATION TECHNOLOGY

Trace-element dispersion patterns, Coeur d'Alene district, Idaho

Some of the known mineral belts and associated geochemical dispersion patterns in the Coeur d'Alene district, Idaho, were founded by G. B. Gott and J. B. Cathrall to be displaced as much as 24 km by post-ore faulting. Through the use of map models relating geochemical dispersion patterns to major faults in the district, the approximate original position and geometric relations of the mineral belts at the time of emplacement of the ore deposits could be determined. These maps revealed that dispersion patterns of As, Cd, Pb, S. and Sb formed huge concentric aureoles around the original positions of monzonite stocks and showed that the major northwest-trending mineral belts were interrupted by these aureoles. The aureoles probably were caused by the heat from the monzonite intrusives during an event that was independent of the formation of the mineral belts.

The picture that emerged from this modeling by geochemical and geologic maps indicated that about 90 percent of the ore that has been mined in the district came from the area of the aureoles around the stocks. Unexplored segments of these aureoles constitute favorable ground for future prospecting.

Studies of alluvial materials from Alaska

Comparison of alluvial materials for use as geochemical sample media.—In a study of minor elements in alluvial materials from the Candle and Solomon quadrangles, Alaska, Sam Rosenblum and T. G. Lovering compared the contents of Ag, Ba, Be, Co, Cu, Ni, Pb, Sn, W, and Zn in 190 magnetic concentrates with those in 267 nonmagnetic concentrates and 274 conventional samples of alluvial silt. The magnetic concentrates proved to be best in locating anomalies of barium, nickel, and zinc. The magnetic and nonmagnetic concentrates were about equal in locating anomalies for beryllium and tin, but the conventional samples of silt were not as effective. Nonmagnetic concentrates were better than the other two media in identifying localities with anomalous tungsten and were equal to the conventional samples of silt in showing anomalous silver. The conventional samples were more effective than the other two media for locating anomalies of cobalt, copper, and lead. Thus, as a group, the concentrates appeared to be the more effective sample media for 7 of these 10 elements.

Contaminants in magnetic concentrates.—Microscopic examination by W. C. Overstreet of 680 magnetic concentrates from Alaska disclosed that detrital magnetite was significantly interwoven with other minerals or with particles of rock. These grains from the subarctic contrasted strongly with the nearly monomineralic detrital magnetite in magnetic concentrates from the humid temperate southeastern United States and the arid subtropics of Saudi Arabia. In the humid temperate region, mineral grains are disaggregated by chemical weathering of the source rocks, and, in the arid subtropics, the grains are separated by thermal shock under extreme diurnal changes in temperature. If frost action is an important factor in degrading rocks in the subarctic, then frost action yields a much less perfect separation of magnetite from other components of the rocks than chemical weathering or thermal shock. The result of this difference, so far as the use of detrital magnetite as a sample medium for geochemical exploration in the subarctic is concerned, is that the abundances of the minor elements show greater dispersion, because of contamination of the magnetite, than those of magnetites from the humid temperate and arid subtropical climatic zones.

Cyanogenic plants affect the geochemical cycle of gold

As a contribution to a study of the geochemistry of gold (Shacklette, 1974) in the weathering cycle, H. T. Shacklette measured the cyanide content of 151 species of plants (mostly trees and shrubs) occurring in 12 vegetation types in Colorado, Nevada, Arizona, and New Mexico. High cyanide concentrations were found in 11 percent of the species analyzed; 10 percent contained low concentrations of cyanide; cyanide was not detected in 78 percent of the species. Some cyanogenic species were found in all 12 vegetation-type areas, which occurred in habi-

tats ranging from alpine to desert. If these selected species secrete cyanide to the extent known for some other species, then large amounts (but probably low concentrations) of cyanide are available to solubilize gold in substrates near the plant roots.

Geochemical and isotopic zoning, Leadville district, Colorado

The zoning of ore deposits in the Leadville district of Colorado, described by Loughlin and Behre (1934), was corroborated in part by J. C. Antweiler III, W. L. Campbell, and E. L. Mosier, by studying variations in the composition of gold and galena and by performing isotopic analyses of lead from galena. Characteristically, when the distance from a center of mineralization in the district increased, the content of silver in gold was found to increase, and the number of other trace elements in the gold was found to decrease. Galena near a center of mineralization contained many trace elements, but, as the distance away from the center increased, the amounts of most elements in the galena decreased, with the exception of magnesium, calcium, strontium, and barium. Lead-isotope analyses showed that lead from the galena becomes increasingly radiogenic away from a center of mineralization.

Selective leaches enhance anomalies in areas of limonite

Representative samples of limonite-impregnated quartzite, shale, sandstone, quartz latite porphyry, and vein material were collected by A. V. Heyl from an area near Pando in Eagle County, Colo., that is characterized by replacement bodies of ferruginous tungsten-bearing jasperoid in middle Paleozoic carbonate rocks. A portion of each sample was leached by J. G. Viets with an oxylate solution to dissolve the limonite, this method being similar to the one developed by H. V. Alminas for the analysis of the limonitic fraction of stream sediments. The dried leachates and corresponding samples of ground whole rock were then analyzed spectrographically by E. L. Mosier. All samples of the ground whole rock in which tungsten was detected showed a strong increase in the tungsten content of the leachate, usually by at least a factor of 10. Other associated indicator elements were similarly enriched in the leachate, as the following data on a typical sample of limonite-impregnated quartzite (table 1) illustrate.

The oxylate leach method thus appears to have strong potential for enhancing geochemical anomalies.

TABLE 1.—*Concentrations of selected elements in a whole-rock sample and its leachate, Pando area, Eagle County, Colorado*

[N, not detected at concentration shown in parentheses. L, detected but in a concentration less than value shown in parentheses]

Element	Whole rock (ppm)	Leachate (ppm)
Mn	300	20,000
Ba	100	7,000
Be	1.5	15
Co	5	200
Cr	30	300
Cu	20	700
La	70	1,500
Mo	N(5)	15
Ni	5	200
Pb	L(5)	200
Sn	N(10)	30
W	20	200

New instrument developed for detecting helium in soils

A portable helium detector developed by Irving Friedman was installed in a four-wheel-drive vehicle for field use. In-place measurements of helium in soil gases were made by driving a steel probe 6 mm in diameter 0.6 to 1.5 m deep into the soil. The measurement took about 1 to 2 min and was precise to ±50 ppb or about one-hundreth of the normal abundance of helium in air. The instrument was used successfully to measure anomalously high values of helium in soils above geothermal areas.

New method for analysis of antimony in geologic materials

An atomic-absorption method was developed by E. P. Welsch and T. T. Chao for determining trace amounts of antimony in geologic materials. The method is rapid and free from common interferences and has a sensitivity that is adequate for geochemical exploration. In this method, antimony in the sample is first volatilized as SbI_3. The released antimony is chelated and extracted by using trioctylphosphine oxide and methyl isobutyl ketone and then analyzed by atomic-absorption spectrophotometry. For a set of 50 samples covering a wide range of geologic materials, the correlation coefficient between values for antimony obtained by the atomic-absorption method and those obtained by the rhodamine-B colorimetric method is 0.94. As many as 80 samples per man-day can be analyzed by the new method.

New compilation of chemical methods useful in geochemical exploration

A compilation of new and refined methods of trace analysis useful in geochemical exploration was made by F. N. Ward. Methods of chemical analysis useful in geochemical prospecting for ore deposits are pre-

sented along with limited repeatability data and some examples of applications. Methods for Ag, As, Bi, Cd, Co, Cu, F, Hg, Mo, Ni, Pb, Sb, Se, and Zn are included. These elements were determined by using molecular or atomic-absorption spectrophotometry, fluorescence, or chemical sensing of ion activity. Thirty-eight trace elements occurring in native gold were determined by semiquantitative emission spectriscopy.

RESOURCE ANALYSIS

Resource data bases

Interest in the USGS Computerized Resource Information Bank (CRIB) data base continued throughout 1974, especially among outside organizations. In November, the Tennessee Valley Authority (TVA) began accessing the CRIB file via its remote terminal at Knoxville. Various types of arrangements also have been made or are being discussed with several other outside organizations. These developments helped to broaden the CRIB data-acquisition system and user community. The Geologic Division is becoming a leader in the data processing of mineral-resource information. In this connection, the CRIB project staff has been called upon with increasing frequency to provide guidance, training, and orientation in data-base design and management for scientists from a number of countries and organizations, including Peru, Bolivia, TVA, ERDA, and the State Surveys of Idaho, Minnesota, Montana, and South Dakota. During 1974, the CRIB file increased to about 85,000 records. CRIB operations became more effective following the implementation of on-line disk storage and the time-sharing mode of operation (TSO).

Further development of the Geologic Retrieval and Storage Program (GRASP) by R. W. Bowen and J. M. Botbol included interactive graphic display of the data accessed by the system. A new data file was added to GRASP for the Branch of Coal Resources by S. M. Cargill and A. C. Olson, namely, USCOAL. This file contains a 16,000-record tonnage inventory of coal resources, indexed by resource categories (for example, depth, thickness, reliability, and rank) and by area (state, county, township/range, and section). USCOAL is the first U.S. data file accessed by GRASP that is a daily production environment; it is being used by the Branch of Coal Resources to answer the many questions received on U.S. coal resources.

Resource estimates

A preliminary estimate by C. S. Bromfield of the lead-zinc potential in possibly concealed carbonate replacement deposits of the Leadville-Oilman type in the central portion of the Colorado mineral belt suggested that ore containing 6 to 18 million tonnes of lead and zinc remains to be discovered. In this area, about 30 million tonnes of lead and zinc have been recovered in 100 yr of mining from deposits of this type discovered in outcrops of pre-Pennsylvanian Paleozoic host rocks. The favorable host rocks are exposed mainly in a narrow band along the flanks of the principal mountain ranges in central Colorado.

Elsewhere in the mineral belt, where these favorable host rocks are not absent through erosion or nondeposition, they are concealed by younger rocks. Speculative resources were estimated on the premise that concealed host rocks are potentially as productive as exposed and maturely prospected rocks.

K. C. Watts, Jr., E. L. Mosier, and H. V. Alminas found that base-metal anomalies, delineated in areas covered by thick Tertiary volcanic sequences in southwestern New Mexico, on the basis of spectrographic analyses of oxalic acid leachates of rock, soil, and stream sediment samples, appear to give evidence of blind postvolcanic mineralization. These presumed leakage halos show a close relationship to major structural and aeromagnetic features within this area.

Mineral resources are known in all the major geographic subdivisions of Alaska and, along with the geology of these mineral resources and the surrounding areas, have been described in reports and maps prepared by Federal and State agencies. These reports and maps have been indexed by 1:250,000 topographic quadrangles and the resulting reference lists released to open files (E. H. Cobb, 1974a–h).

Resource model studies

Analysis by D. A. Singer, D. P. Cox, and L. J. Drew (1975) of the average grades and total tonnages of porphyry, stratabound, and massive sulfide copper deposits has shown that tonnages and grades are approximately lognormally distributed; this distribution makes it possible to predict the probability of various grade-tonnage classes for a resource estimate. In addition, the discovery that grades are independent of tonnages for porphyry copper deposits suggests that very large tonnage, low-grade deposits are just as rare as very large tonnage, high-grade deposits.

The exploration play mechanism was found by L. J. Drew (1975) to be the fundamental unit by which petroleum resources are converted into reserves. A two-stage regression model of the exploration process was constructed in which the wildcat drilling rate and the deposit discovery rate are explained in terms of a suite of economic and physical variables. Several important conclusions were reached when this model was used to analyze the exploration history of the Powder River Basin, Wyo.: (1) the rate at which wildcat wells were drilled is highly correlated with the discovery expectations of the exploration operators; (2) the number of deposits discovered is highly correlated (nonlinear) with the wildcat drilling rate; (3) the aggregate volume of petroleum discovery is independent of the wildcat drilling rate; (4) a learning effect was found to occur within an exploration play; and (5) the rate at which deposits were discovered is independent of the level of physical exhaustion of the basin. For the most part, these results are a direct consequence of the manner in which the exploration play mechanism operates.

A comprehensive data storage and retrieval system for the DEC 10 System was designed by J. K. Pitman to estimate oil yield, thickness, and resources on the basis of oil-shale Fischer assay and saline mineral data for core holes in Colorado, Utah, and Wyoming. These estimates have provided the basic data for evaluating lands involved in exchanges between the Federal Government and private industry, as well as for determining areas suitable for in-place or underground recovery methods.

Mineral resources and geology of South Dakota

A comprehensive report entitled "Mineral and Water Resources of South Dakota" was published in 1975 by the U.S. Senate Committee on Interior and Insular Affairs and as a bulletin of the South Dakota Geological Survey. This report is a greatly revised edition of a similar volume issued in 1964. Senator George McGovern requested that the USGS be the lead agency in preparing the new edition; other contributing organizations were the South Dakota Geological Survey, the South Dakota School of Mines and Technology, the U.S. Bureau of Reclamation, and the U.S. Bureau of Mines. J. J. Norton was editor of the mineral-resource and geologic sections of the report.

Flat-lying sedimentary rocks are at or near the surface over most of the State. In the west, however, the most striking feature is the Black Hills, a domal uplift with Precambrian rocks exposed in its core and a belt of Tertiary intrusions crossing its northern end. East and northeast of the Black Hills is a thick lens of sedimentary rocks constituting the southern part of the Williston Basin. Other aspects of the subsurface geology across the State are less pronounced. Precambrian rocks reappear at the surface in the southeast and northeast. The drainage system of the region is dominated by the Missouri River, which bisects the State. East of the river, much of the surface has a cover of glacial deposits.

The Black Hills have the chief mineral deposits, mainly because their Precambrian rocks are the source of the gold that has furnished more than half of the nearly $2 billion mineral output of the State. The several pegmatite minerals (feldspar, mica, lithium minerals, beryl, and tantalite-columbite), as well as decorative stone and mineral specimens, have also been important, and taconite iron will ultimately become a significant contributor to the economy. Sedimentary rocks on the flanks of the Black Hills have gold-silver, lead-silver, and tungsten deposits and also bentonite, other clays, uranium, and gypsum. South Dakota is unique in having a State-owned cement plant, which is located in Rapid City on the eastern side of the Black Hills and draws its raw materials from nearby. Oil output from the South Dakota segment of the Williston Basin is small but rapidly increasing. Lignitic coal is abundant in the northwestern part of the State, although none is being mined now. Granite dimension stone is the basis for a small but significant industry near the northeastern border of the State. Production of sand, gravel, and crushed stone is, as in all States, an important industry.

The report treats each resource in some detail and covers, as well, all aspects of the geology that bear on exploration and development. Chapters on geophysics and geochemistry show that these fields may have much more to offer in South Dakota than they have yielded thus far. Examination of the environmental effects of resource development indicates that damage has been spotty and can in the future be eliminated or brought within reasonable limits. In addition to its other uses, the volume serves as a guidebook to the geology of South Dakota.

Many maps show the geology and the distribution of resources. One of the maps is a new attempt to organize the Precambrian rocks of the Black Hills into a plausible stratigraphic and structural arrangement. This map should facilitate exploration for gold because it indicates where rocks of the kind containing gold deposits (especially the famous Homestake deposit) are likely to be found in the

subsurface. Another map shows the locations of all the oil tests ever drilled in the State.

Gold almost certainly will continue as South Dakota's most important mineral product. The outlook for finding new deposits is especially favorable. The authors of the report indicate that other commodities also show promise. The ones that most deserve increased attention are iron, oil, coal, uranium, lead-silver, decorative stone, molybdenum, and zeolites.

COAL RESOURCES

U.S. coal resource estimate increased 23 percent

According to a recent compilation by Paul Averitt (1975), the revised estimates of U.S. coal resources remaining in the ground as of January 1, 1974, total 3,600 billion tonnes. This huge tonnage constitutes about one-fifth of the total world supply. The revised figure is 23 percent more than previous recent estimates; the increase is based on geologic mapping, exploration, and study conducted during the last few years by Federal and State governmental agencies and by private industry. Resources of 1,570 billion tonnes have been identified by mapping and exploration, and an additional 2,030 billion tonnes, classed as hypothetical, are estimated to be present in unmapped and unexplored areas and in the deeper parts of known coal basins.

Uranium in coal of the northern Great Plains

V. E. Swanson reported that the possibility of recovering uranium as a byproduct of coal combustion and the apprehension of environmental contamination by radioactive products in the vicinity of coal-fired electrical generating plants have inspired a renewed widespread interest in the uranium concentration in coal of the northern Great Plains. Approximately 250 samples of subbituminous coal and lignite were chemically analyzed for 43 elements as a part of the Department of Interior's Northern Great Plains Resource Program (V. E. Swanson, Claude Huffman, Jr., and J. C. Hamilton, 1974; U.S. Geological Survey and Montana Bureau of Mines and Geology, 1974). The samples represented coal from all of the 15 major operating mines in the region and from 40 cores in areas proposes to be mined in the future. Uranium contents of the 250 coal samples were determined by H. T. Millard, Jr., using the delayed neutron activation method. The following data compiled from the analyses may dispel concern:

1. The mean uranium content of the coal is 0.9 ppm; the range is 0.1 to 7.5 ppm U.
2. The average uranium content of coal shipped from eight major lignite mines in western North Dakota and eastern Montana is 1.0 ppm, and from individual mines it ranges from 0.8 to 1.2 ppm. The average uranium content of coal shipped from the seven major subbituminous mines in the Powder River Basin is 0.8 ppm, and from individual mines it ranges from 0.4 to 1.1 ppm.
3. Uranium is nonreactive and nonvolatile at the temperatures of powerplant combustion, so the element is concentrated in the ash, a fact supported by analyses of bottom- and fly-ash samples from power plants. If, for example, a coal contains 1.0 ppm U and 10 percent ash, the powerplant ash contains 10 ppm N.

Coal in the Powder River Basin in Wyoming and Montana

A study by N. M. Denson, W. R. Keefer, and J. H. Dover revealed that the low-sulfur subbituminous coal beds extending over a wide area in the Powder River Basin in Wyoming constitute one of the world's largest known coal deposits and are prime targets for future mining. One prominent bed, the Wyodak-Anderson coal, ranges from 15 to 30 m in thickness and lies at depths of less than 61 m in a strip 130 km long and 3 to 5 km wide (approximately 75,000 ha) (Denson and Keefer, 1974; Denson, 1975). The bed contains approximately 13 billion tonnes of coal in the tract that lies 61 m or less below the surface. Available analyses of the coal indicate averages of less than 1 percent S and 6.3 percent ash and a heat value of 21 million J/kg. The study is based on sonic-density, gamma-ray, and electric logs from numerous oil and gas tests and from recent coal drill-hole data compiled by the Montana Bureau of Mines and Geology.

A preliminary evaluation of the distribution of coal beds in the Recluse mine site model area in northern Campbell County, Wyo., was made from 340 geophysical well logs by R. G. Hobbs, E. R. Landis, A. R. Norton, and J. D. Sanchez. Seven persistent, named coal beds were traced in the Tongue River Member of the Fort Union Formation of Paleocene age in a rectangular area of four 7½-min quadrangles. A drill program is underway to obtain core samples that will be analyzed to determine the quality and composition of the coal and the characteristics of the intervening rocks. These geologic and geochemical data and additional resource, geophysical, and hydrological information will be used to determine the critical, geologically related parameters

necessary for the development of the natural resources in the model area.

Lignite resources, Denver basin

P. E. Soister (1974) estimated that between 9 and 18 billion tonnes of lignite underlie part of the Denver basin in an area approximately 48 km wide and 120 km long from near Denver to south of Ramah and Calhan, Colo. Three lignite beds present in most of the area range from 3 to 16.6 m in thickness locally and average between 3 and 8 m thick regionally.

Coal beds related to tectonics in Utah

Detailed stratigraphic studies by Fred Peterson (1969) in Kane County, southern Utah, indicated that the subsidence of the Kaiparowits structural basin and the development of three northwest-trending anticlines within the basin significantly influenced the distribution and thickness of commercially valuable coal deposits in the Upper Cretaceous Straight Cliffs Formation. Regionally, most of the coal beds thicken northwestward toward the deeper part of the Kaiparowits basin. Locally, the coal beds thin over the crests of the ancestral Nipple Bench, Smoky Mountain, and Rees Canyon-Rock Creek anticlines. The areas of thinner coal demonstrate that continued or recurrent movement immediately preceding the classic Laramide orogeny occured on these structural features during middle Turonian-early Campanian time. If areas of active growth of structural features during deposition are properly identified and evaluated with respect to the local structural setting, clastic sediment sources, and shoreline trends, knowledge of them may prove valuable for coal exploration, development, and resource evaluation in other parts of the Colorado Plateau.

Deformed coal in the Bering River coalfield, Alaska

Thick coal is spectacularly exposed locally in the Bering River coalfield in Alaska. The coal beds appear to change thickness abruptly; the extent and continuity of individual beds are difficult to determine because of the complex structure of the coal-bearing strata. According to recent studies by R. B. Sanders, the coal was found in boudinlike pinches and swells along the limbs of folds, along fault planes, and especially in dilations along the axes of what appears to be a series of faulted chevron folds. The coal ranges in rank from low volatile bituminous to semianthracite, has a low sulfur content, and is, in part, of coking quality. The highest rank coal is found in apparently more continuous beds located within the easternmost part of the coalfield, where structure appears to be less complex.

Supplemental bibliography and index of coal-related publications

A bibliography and index of about 200 coal-related reports and maps published by the USGS during the 3½-yr period January 1971 through June 1974 were compiled by F. K. Walker (1975). The listings are supplemental to those in USGS Bulletin 1377 (Averitt and Lopez, 1972). Most of the publications cited may be consulted in large public libraries and in most college and university libraries; some that are not yet out of print can be ordered from the USGS.

OIL AND GAS RESOURCES

Possible petroleum accumulations in Baltimore Canyon Trough area, offshore Atlantic Ocean

In the mid-Atlantic area (Baltimore Canyon Trough area), Lower Cretaceous rocks, which probably contain (1) marine sandstones associated with deltaic sequences and (2) terrigenous sediments interfingering with carbonates, are prospective petroleum targets (W. J. Perry, Jr., and others, 1974). These Lower Cretaceous sediments extend from about 1,500 m below the water bottom to 6,100 m along the axis of the Baltimore Canyon Trough. According to R. Q. Foote, trapping mechanisms for petroleum on the shelf in the Baltimore Canyon Trough area are expected to fall into four categories: (1) relief over piercement structures (igneous intrusions and salt domes), fault blocks, and possible reefs; (2) possible reefs; (3) stratigraphic traps; and (4) closure against faults.

The preliminary results of a seismic survey indicate that a Cretaceous reef structure may underlie the Continental Slope in the Baltimore Canyon Trough area (R. E. Mattick, unpub. data, 1975). Petroleum may have migrated from potential source beds beneath the slope and rise and been entrapped in the reef (E. C. Rhodehamel, unpub. data, 1975). This structure, even though it is in water depths of 1,200 m, could prove to be a significant petroleum trap.

Revised petroleum data for the Appalachian basin

The area of the Appalachian basin, which is of interest to the petroleum geologist, lies between the crest of the Cincinnati arch extended on the west and the western edge of the Blue Ridge anticlinorium, the Reading Prong, and the Hudson Highlands

on the east; the southern side of the Adirondack Mountains or the Canadian border on the north; and the northern edge of the overlapping Gulf Coast Cretaceous rocks to the south in Alabama. According to Wallace de Witt, Jr., the basin covers about 540,450 km^2 and is subdivided along the Allegheny front into the larger, western, generally petroliferous Appalachian Plateaus, covering 424,300 km^2, and the eastern, smaller, generally petroliferous, structurally complex Valley and Ridge, province, covering 116,000 km^2.

To date, more than 2.5×10^9 bbl of oil have been produced in the basin, almost all from rocks underlying the Appalachian Plateaus. More than half of this volume, 1.7×10^9 bbl, came from strata of Devonian age, and more than 75 percent occurred in quartzose clastic reservoir rocks. Remaining reserves producible by existing methods amount to about 3.0×10^8 bbl. In contrast, sparse data suggest that the volume of currently nonproducible oil remaining in reservoir rocks of the Appalachian basin ranges from 8×10^{10} to 12×10^{10} bbl. Producing any quantity of this oil will require extensive drilling in the relatively untested parts of the basin, including the eastern half of Lake Erie, as well as the development of new and imaginative techniques for improved recovery in areas of oil production, which may or may not have been partly enhanced by secondary recovery methods in addition to the original period of primary production.

Paleogeographic reconstruction—a method for estimating crustal shortening in the southern Valley and Ridge province of the Appalachian basin

L. D. Harris found that integration of regional stratigraphic data from many surface sections of the Nolichucky Shale in several fault slices northwest of the Saltville thrust outlines a lobate algal stromatolite bank in this Late Cambrian formation. Because the algal bank has limited geographic extent, both edges could be identified from northwest to southeast in the Pine Mountain, Wallen Valley, Clinchport, and Copper Creek fault belts. The faults transect the algal bank at a wide angle, which juxtaposes bank and nonbank facies of the Nolichucky across the thrust.

Paleogeographic reconstruction of the bank from facies data in the several fault slices gave a reasonable configuration for the bank before thrusting. By fitting individual thrust slices into their proper geometric position in the original bank, on the basis of the shape and extent of the segment of the bank within each fault slice, the amount of movement on the Pine Mountain, Wallen Valley, Clinchport, and Copper Creek thrusts can be estimated as approximately 64 km.

Although these data apply only to the western half of the Valley and Ridge province, they suggest that a similar or greater amount of shortening may have occurred between the Saltville thrust and the western edge of the Blue Ridge thrust.

Although this method for estimating crustal shortening requires an abundance of good stratigraphic data and the presence of well-defined identifiable facies in several thrust slices, it may be readily applicable in other parts of the Valley and Ridge or in tectonically similar areas such as the Foothills belt of western Canada.

Pennsylvanian sedimentation, Carbon, Sweetwater, and Fremont Counties, Wyoming

Detailed examination and description of rocks and bed forms in cores drilled in the Lost Soldier and Wertz oil fields, south-central Wyoming, by M. W. Reynolds, T. S. Ahlbrandt, J. E. Fox, and P. W. Lambert (unpub. data, 1975) demonstrated that the Pennsylvanian Tensleep Sandstone was deposited in an interfingering succession of shoreface, foreshore, and eolian dune and interdune environments. The shoreline fluctuated across an 8-km belt between the oil fields, so that Tensleep strata at Lost Soldier oil field on the west are of mixed shoreface and foreshore facies, whereas the strata at Wertz oil field on the east are dominantly of foreshore and eolian origin. Only during deposition of the upper part of the Tensleep did eolian deposits regress westward across the area of the Lost Soldier field. The distribution of oil, cementation, and fractures in the facies support the existing interpretation that oil accumulation in the Lost Soldier field was controlled late by fractures, whereas the control of accumulation in the Wertz field resulted from a combination of facies and cementation, the fracturing playing a less important role than it did at Lost Soldier.

Continental sedimentation and hydrocarbons in Tertiary rocks, northeastern Utah

More than 750 million barrels of measured, indicated, and inferred oil reserves have been discovered in stratigraphic traps in marginal and open lacustrine facies of the Green River Formation. Delta-front, distributary channel, and overbank sandstones are the primary reservoir units. Overpressured reservoirs are found in the lower part of the Green River Formation above the Colton Formation and in the Flagstaff Member of the Green River Forma-

tion; these reservoirs are at depths generally below 3,000 m west of the Green River, where lacustrine rocks abruptly change facies laterally to the relatively impermeable alluvial and open lacustrine facies that serve as part of the trap mechanism, according to T. D. Fouch, 1975a. Nonassociated gas is produced from stratigraphic traps in marginal lacustrine rocks of the Green River Formation and from traps within the paludal-alluvial facies of the North Horn Formation and the Wasatch Formation. Channel sandstones and associated overbank sandstones serve as reservoirs for gas in nonlacustrine rocks. Fouch (1975b) has found that traps are related to the following: (1) change in clay content of the sandstone within a single channel, (2) change from one genetic sandstone type to another, and (3) regional facies changes. Excellent potential remains for stratigraphically trapped gas.

Petroleum source-rock studies, Permian System

E. K. Maughan has found that the organic-rich Meade Peak and Retort Phosphatic Shale Members of the Permian Phosphoria Formation in western Wyoming and adjacent parts of Utah, Idaho, and Montana are probable source beds of the oil and gas found in upper Paleozoic rocks of the region. The Meade Peak and Retort contain as much as 8.8 percent residual organic carbon. Some thin beds in the Meade Peak and Retort contain as much as 30.7 and 21.4 percent organic carbon, respectively.

The Meade Peak occupies an area of approximately 115,000 km^2 and has a maximum thickness of about 50 m in eastern Idaho and northern Utah. The Retort occupies an area of approximately 100,000 km^2 and has a maximum thickness of about 35 m in southwestern Montana and in central western Wyoming. Volumetrically, the Meade Peak comprises about 2,025 km^3 and the Retort about 1,225 km^3 of sediment.

The Phosphoria Formation was deposited along the Continental Shelf east of the late Paleozoic mobile belt. Subsequently, at least 2 km of overlying sediment was deposited by the end of the Triassic in the western part of the region and, because of slower rates of deposition, by the end of the Cretaceous in the eastern part of the region. This depth of burial probably produced adequate pressure and temperature for generation of hydrocarbons from the organic substances.

An attempt was made to exploit the Retort as an oil shale near Dillon in southwestern Montana, where it yielded an average of 84 l of oil per tonne. Elsewhere, Fischer oil assays yielded little or no petroleum from the Retort; the Meade Peak, where it has been tested, seems to be below detectable limits.

Organic-rich Devonian eugeosynclinal rocks in north-central Nevada

F. G. Poole found that the allochthonous Devonian Woodruff Formation in the Pinon Range, southwestern Eiko County, Nev., locally contains as much as 17 percent organic carbon and yields as much as 5,200 ppm soluble hydrocarbons. The Woodruff, which consists principally of dark-colored marine chert, mudstone, siltstone, minor sandstone, and limestone and dolomite, is believed to have been deposited in a Devonian marginal ocean basin west of the continental edge and east of an offshore island arc. The eugeosynclinal Woodruff deposits were subsequently deformed and obducted eastward onto the Outer Continental Shelf as part of the Roberts Mountains allochthon during the Late Devonian and Mississippian Antler orogeny. Palynomorph and conodont alteration colors indicate a postdepositional history of persistent low temperatures that probably never exceeded 100°C, and it seems possible that organic matter in the Woodruff could have generated petroleum in the late Paleozoic. Similar Paleozoic eugeosynclinal rocks in the Western United States should be examined and evaluated for their petroleum potential.

Petroleum source beds in the Pilot Shale of the eastern Great Basin

The Upper Devonian (lower Famennian) lower unit of the Pilot Shale has been found to contain dark-gray mudstone and limestone beds of sufficient thickness, areal distribution, and organic richness to merit consideration as source beds for petroleum generation, according to C. A. Sandberg and F. G. Poole. The interval of lower Famennian source beds, which lies between the Lower *Palmatolepis crepida* and Lower *P. marfinifera* conodont zones, is 93 m thick, has an average organic carbon content of 2.2 percent, and yields about 160 ppm total soluble hydrocarbons in the Confusion Range, Utah. The lower unit of the Pilot was deposited on a miogeosynclinal carbonate shelf in a rapidly subsiding basin centered in White Pine County, eastern Nevada, and adjacent Millard County, Utah. Alteration colors of contained conodonts indicate that these source beds were never subjected to temperatures in excess of 90°C in Utah and 140°C in Nevada. These beds may have generated and expelled petroleum for distant eastward migration into the western Rocky Moun-

tains region as well as for local accumulations within adjacent formations in western Utah.

Neogene stratigraphy and structure, California continental borderland

Bedrock samples collected along geophysical traverses on the California continental borderland show that Neogene strata constitute most of the exposed bedrock south of the northern group of Channel Islands and west of the mainland shelf. Preliminary study of these rocks by J. G. Vedder, L. A. Beyer, Arne Junger, G. W. Moore, A. E. Roberts, J. C. Taylor, and H. C. Wagner (1974) indicated that they are composed primarily of hemipelagic calcareous claystone with subordinate amounts of volcanogenic and terrigenous detritus at places. Microfossil assemblages identified and correlated by R. E. Arnal and J. D. Bukry show that most of Miocene time is represented by truncated stratal sequences along the crest of Santa Rosa-Cortes Ridge. Miocene volcanic rocks are concentrated on the compound-ridge system that connects Santa Cruz Island, San Clemente Island, and Santa Catalina Islands and that extends southeastward to Fortymile Bank. These volcanic rocks range in composition from rhyodacitic to basaltic but are chiefly andesitic. Thick sequences of Pliocene strata (>400 m) are restricted to topographic basins except for local areas on and near the mainland shelf.

In general, major structures inferred from geophysical surveys trend northwest throughout the borderland south of the northern island group. One exception is the east-trending fault zone that forms the northern edge of the San Nicolas basin. Normal, reverse, and strike-slip separations are inferred on faults that range in age from Miocene to Holocene. Large folds in the outer ridges and basins are nearly symmetrical and have low amplitudes and broad wavelengths, in contrast to those along the mainland coast. Possibly early Miocene, late Miocene, and Pliocene unconformities of local extent are recognized on acoustic-reflection records, which were interpreted by Junger and Wagner.

Development of substantial structural relief is suggested by the presence of locally derived clastic detritus in some early and middle Miocene strata. The restriction of thick Pliocene sequences to basins implies the existence of a well-defined basin and ridge topography by that time.

Some of the shaly units that range in age from early Miocene to early Pliocene contain sufficient organic matter to generate fluid hydrocarbons if their deformational and thermal histories have been appropriate. Structures suitable for large accumulations of petroleum are commonplace; but, until these structures are tested for their reservoir characteristics, resource appraisals will remain conjectural.

Measured sections of West Foreland and Tyonek Formations, Kenai Peninsula Borough, south-central Alaska

Exposure of Tertiary rocks on the northwestern flank of the Cook Inlet basin near Capps Glacier and along Chuitna River were measured, described, and sampled in detail for heavy-mineral and palynological studies by W. L. Adkison, J. S. Kelley, Jr., and K. R. Newman (1975). The rocks are assigned to the West Foreland and Tyonek Formations. The West Foreland, possibly of Eocene age, consists of a conglomerate 366 m thick and lies unconformably on Mesozoic rocks. In the basin to the southeast, the Hemlock Conglomerate overlies the West Foreland and is the most important oil reservoir in the area. At the exposure near Capps Glacier, the Hemlock is missing because of erosion or nondeposition. This conclusion is based on the palynological determinations by Newman and on a heavy-minerals study by Kelley (unpub. data, 1975). The Tyonek Formation, which unconformably overlies the West Foreland, consists of conglomerate and sandstone in the lower part and sandstone, siltstone, and coal in the remainder. The total thickness exceeds 671 m. Stratigraphic relationships between four measured sections were only partly determined because of major faulting or the lack of exposures in large areas. These measured sections provide valuable surface control for subsurface stratigraphic units that produce oil and gas in the Cook Inlet Tertiary basin.

Energy resources of the Earth

M. K. Hubbert (1972) described the Earth's energy resources as consisting of three continuous energy fluxes and of certain stores of energy beneath the Earth's surface. The continuous energy fluxes are: (1) solar radiation at a rate of $174{,}000\times10^{12}$ thermal watts; (2) geothermal energy, 32×10^{12} W; and (3) tidal energy, 3×10^{12} W. The stores of energy within an accessible depth of about 10 km beneath the Earth's surface consist of thermal energy, the chemical energy of the fossil fuels, and nuclear energy.

During the last million years, the human species has risen to a position of dominance among the world's animals by progressively developing means for controlling ever-larger amounts of these energy resources, particularly the fossil fuels. This control has made possible the rise of the present industrial

civilization; it has also created one of the most drastic ecological disturbances of the Earth's plant and animal populations ever known. Most of this disturbance has occurred during the last century, and it is estimated that the bulk of the world's oil will be consumed within the next 60 yr, and the bulk of all kinds of fossil fuels within the next 3 centuries. For the United States, the peaks in the production of both oil and gas have already been passed, and most of the remaining oil and gas will be consumed by the end of the present century. Ultimately, if such a civilization is to survive, it must be based upon a sustained energy source of an appropriate magnitude. The most likely choice for this source eventually will be the energy from solar radiation.

Oil reserves of deep basins

Investigations by L. C. Price and M. A. Ratcliff, Jr., provided evidence of a hot, deep origin and migration of crude oil. Areas of investigation include the organic geochemistry of shales and crude oils and the geology of oil occurrence. One study shows that oil gravity correlates more strongly with the salinity of associated waters than with depth and thus suggests that changes occurring in reservoired crude oils with increased depth are due to crude-oil degradation and not to thermal cracking. Thus, we might expect to encounter reservoired crude oil at depths much greater than those predicted by more conventional hypotheses. Detailed examination of oil occurrence in many different basins has shown that the oil occurs precisely where it should if it is moving up from the deep basins along faults. Thus, this model offers a powerful new oil-exploration tool. Geochemical-geologic evidence also shows that we may expect large reserves of dissolved crude oil in deep-formation waters of some sedimentary basins.

Organic matter and hydrocarbons in barrier island quartzose sands

Field and laboratory studies by J. G. Palacas, P. M. Gerrild, A. H. Love, and A. A. Roberts of three quartzose sand facies of barrier islands extending from Pascagoula, Miss., to Tarpon Springs, Fla., showed that the relative amount of organic constituents is as follows: pond facies>lagoon facies>marine facies. In the same order, average organic carbon contents were about 0.3, 0.1, and 0.05 percent, and hydrocarbon contents were 10, 3, and 1.5 ppm. Gas chromatographic data and quantitative parameters indicated that the hydrocarbons were derived from aquatic and terrestrial organisms and were not due to oil pollution. Hence, the hydrocarbon contents in these sands are considered as baseline concentrations. With regard to later diagenesis and the origin of petroleum, if approximately 5 percent of the organic matter were thermally converted to petroleum at depth, then 50 to 300 ppm of hydrocarbons could be generated in these relatively clean sands. These amounts of hydrocarbons in sand would then represent a potential source for ready migration and accumulation of petroleum.

Origins of natural gases in Montana

Three basic types of natural gas in Montana have been identified by D. D. Rice (1975): (1) gas of biogenic origin (immature); (2) gas occurring with oil, designated associated gas (mature); and (3) high-temperature gas (postmature). Most Montana gas is biogenic, generated from predominantly marine organic source material. Biogenic gases are produced near the surface and to depths of 800 m by anaerobic bacteria. This gas is characterized by a high methane (CH) content (>90 percent) and by enrichment in the light C^{12} isotope (δC^{13}, −60 permill). As depth and (or) temperature increase, thermal metamorphism predominates, and associated gas is formed. This gas has a higher content of heavier hydrocarbons and a greater C^{13}/C^{12} ratio (δC^{13}, −55 to −45 permill). In some areas surrounding the Bearpaw Mountains and Sweet Grass Hills, which were sites of Tertiary igneous activity, high-temperature gas was generated. This gas is distinguished by a further increase in the C^{13}/C^{12} ratio (δC^{13}, −40 permill) and high methane content. Some biogenic gases have been altered by thermal metamorphism to form gases of mixed origin.

The identification of gas types by origin, when combined with an analysis of all geologic factors, is an invaluable aid to the exploration geologist. He can identify new areas for exploration, predict the type of accumulation that should occur, and estimate reserves.

Possible petroleum prospect located in Denver basin

A possible petroleum-related geochemical anomaly in surface rocks in the Denver basin near Boulder, Colo., was identified during the summer and fall of 1974. The chance discovery resulted when T. J. Donovan and R. L. Noble (1975) were developing aerial reconnaissance and mapping techniques using light aircraft as an observation platform. The geochemical anomaly is halo shaped and suggests a

prospective area of about 20 km^2. Regional subsurface data support the possibility of a buried deposit in Cretaceous sandstone reservoirs.

Portable helium detector for energy resource exploration

Preliminary work by A. A. Roberts, Irving Friedman, T. J. Donovan, and E. H. Denton (1975) indicated that a helium-survey technique may be applicable as an exploration tool for geothermal resource areas, as well as for petroleum and natural-gas deposits. Using a portable mass-spectrometer-type leak detector, they were able to show anomalously high helium concentrations in soil gases near hot springs and other abnormally warm areas. In contrast, the soil gases near cold regions have contained only the normal background level of helium. Further preliminary work suggests anomalous helium concentrations in soil gases over petroleum deposits.

Manganese as a petrolum pathfinder element

T. J. Donovan, R. L. Noble, Irving Friedman, and J. D. Gleason (1975) showed that manganese concentrations in the carbonate lattices of surface-cemented rocks overlying petroleum deposits vary in a systematic and mappable way that appears to reflect the subsurface distribution of petroleum. The concentrations typically range through one or two orders of magnitude and have been found over known and suspected oil deposits. Both anomalous apical and aureole patterns over anticlinal traps have been documented. The preliminary data suggest that manganese may be a suitable petroleum pathfinder element for geochemical-exploration programs.

Summary of factors controlling porosity distribution

J. E. Fox, P. W. Lambert, R. F. Mast, N. W. Nuss, and R. D. Rein have found that a general critical depth appears to be controlling the degree of porosity. At depths less than approximately 3,050 m in the Bighorn and Wind River Basins, Wyo., and less than approximately 2,440 m in the greater Green River Basin, Wyo., the porosity of the Tensleep is highly variable and ranges from 2 to 26 percent and 2 to 12 percent, respectively. Petrographic indications are that several types of cements control the porosity at these shallower depths. These cementing agents include calcite, dolomite, anhydrite, and secondary silica. At depths greater than approximately 3,050 m and 2,440 m, the variability of porosity is less, ranging from 2 to 6 percent. At these greater depths, dominantly quartz overgrowths and secondary silica cement fill the pore spaces. These probably reflect the influence of greater pressure on the more deeply buried arenaceous sandstone. The degree of porosity can be predicted more easily below the critical depth than it can be at shallower depths, where it is more variable.

Applications of chalk diagenesis to petroleum-exploration problems

Petrographic, scanning-electron-microscopic, and oxygen-isotopic analyses of chalk samples from 22 wells in the North Sea area, plus Deep Sea Drilling Project (JOIDES) cores and outcrop samples from England and Ireland, indicated to P. A. Scholle that an orderly sequence of diagenetic changes occurs with progressively deeper burial. Burial is accompanied by loss of porosity (hardening) due to redistribution of carbonate by pressure solution. The reprecipitated carbonate forms mainly as overgrowths on coccolith plates and as fillings of foram chambers. At the same time, progressive recrystallization leads to alteration of the bulk-oxygen-isotopic values of chalks. As a result, these isotopic values can be used to determine maximum depth of burial of chalks (and their associated section), paleogeothermal gradients, and proximity to zones of deformation. The termination of further diagenesis by oil entry into the chalks can be used to date the time of oil migration into the reservoir. Chalks containing oil have anomalously high porosity and unusually slight recrystallization for their depth of burial, indicating that the presence of oil may have helped retain favorable reservoir characteristics.

Isotopic analysis can be used with full cores, sidewall cores, or cuttings, and, unlike most organic geochemical methods, it does not require special sample handling. Application of this technique allows the regional mapping of paleogeothermal patterns and may enable the detection of ancient thermal highs and structurally deformed zones from sample points 10 to 50 km away.

New method for determining environmental history by using corals, Dade and Monroe Counties, Florida

Massive coral heads, *Montastrea annularis*, were cored by J. H. Hudson and R. B. Halley with a newly developed hydraulic coring device at Hens and Chickens Reef off Snake Creek in the Florida Keys. Hens and Chickens Reef was selected because it was observed by E. A. Shinn to have suffered severe mortality in the latter part of 1969. Although this time period had an unusually severe cold weather, blame for coral deaths was attributed to manmade

factors by some, such as (1) silt from dredge operations, (2) aerial mosquito spraying on the nearby Florida Keys, (3) septic-tank leakage through porous limestone into marine environments, and (4) oil pollution. Tree-ringlike annual density bands revealed in X-radiographs of coral cores showed that the coral growth rate at Hens and Chickens has remained constant over the past 40 yr; this constant rate shows no signs of man's activities. Corals that survived the 1969 event continued to grow at the same annual growth rate (approximately 1 cm) as they did in the early 1940's, when human population and development were far less significant than they have been in the past 10 yr. The event that killed 80 percent of the corals at Hens and Chickens in 1969 is clearly recorded in X-radiographs of the surviving corals as a "stress band" of unusual density. Other stress bands that correlate with unseasonably low temperatures occurred in 1964, 1958, and 1942. The 1942 stress band is of even greater density than the one associated with the 1969 kill. Use of the permanent tree-ringlike method, in combination with oxygen-isotope temperature analysis, will allow environmental reconstruction of the past 500 yr or more and thus provide researchers a baseline upon which to evaluate man's recent impact on the tropical and subtropical environment. The method also allows comparison of modern coral growth rates with those of corals of Pleistocene age, which built up what are now the Florida Keys some 125,000 yr ago.

Physical properties data banks to become a reality

As a part of the USGS Energy Resources Program, C. K. Fisher reported a proposal to establish a national system of core libraries, operated permanently by either State Surveys or an equivalent agency and supported by Federal, State, university, and industry funds. The USGS will provide a large part of the initial investment needed to organize and develop these facilities. Preliminary planning has indicated that 8 to 10 core libraries will be needed to properly accommodate the material in all regions of exploration activity, both onshore and offshore. New facilities will be established to complement existing State repositories, and support money for expansion and operation of the established facilities will be made available, hopefully, beginning in fiscal year 1977. A core repository for the Rocky Mountain area is now being developed near Denver for any material not required or requested by a State agency. Also, steps are being taken to provide financial support for the operating fund of an industry-State-Federal cooperative core facility at California State College in Bakersfield.

Secondary recovery of oil via microbial stimulation

To determine microbiological-biochemical techniques that may accelerate or optimize water-injection methods now being used in the field for secondary recovery of oil, some preliminary laboratory studies were made by F. E. Senftle and F. D. Sisler. These studies show that microorganisms that produce surface-tension-reducing chemicals during oxidation of petroleum hydrocarbons (a desirable end product of metabolism that increases migration of oil through dense formations) reach a temporary end point when these surfactant chemicals cause autolysis of cells. This effect can be controlled by continuous introduction of additional water and nutrients.

OIL-SHALE RESOURCES

Fossil-bearing pebbles in the Uinta Formation, Piceance Creek basin, Colorado

In the east-central part of the Piceance Creek basin, Colo., a lenticular bed of conglomerate, which included a few fossil-bearing pebbles, was found by R. B. O'Sullivan near the top of the Uinta Formation of Eocene age. The angular dark-gray cherty limestone pebbles were as much as 20 mm across and contained fusulinids and impressions of brachiopods and crinoid stems. The fusulinids were poorly preserved but appeared to be of Late Pennsylvanian or Early Permian age. The pebbles suggest that Paleozoic rocks were exposed, possibly to the east of the Piceance Creek basin, during deposition of the Uinta Formation.

Marlstone stratigraphic marker beds in the Uinta Formation, Colorado

Mapping by W. J. Hail, Jr., in the south-central part of the Piceance Creek basin, Colo., showed that certain marlstone beds continue to provide useful stratigraphic markers for subdividing the dominantly clastic Uinta Formation of Eocene Age. Two previously unmapped marlstone units found in the upper part of the Uinta Formation in the upper Stewart Gulch area south of Piceance Creek were mapped and are thought to be tongues of the Parachute Creek Member of the Green River Formation. Although both the marlstone units in the Uinta Formation and the tongues of the Parachute Creek Member of the Green River Formation found in the Uinta Formation locally contain oil-shale beds, the beds are too thin or too low in grade to be of economic value.

Contribution of analcime to silicon concentration in caustic leachates from pyrolyzed oil shale

Investigations by G. A. Desborough of hot-water leaching on analcime-bearing and analcime-free nondawsonitic spent-shale residue obtained from Fischer assays showed that pyrolyzed analcime-bearing oil shale contributes more water-soluble sodium, aluminum, and silicon than analcime-free oil shale. The total amount of dissolved solids leached from the spent shale is largely a function of the mineralogy of the oil shale. Examination of the leachate obtained after hot caustic leaching of the analcime-bearing and analcime-free oil-shale residue from Fischer assays showed that analcime contributed significant amounts of silicon to the leachate. This silicon may inhibit hot caustic extraction of aluminum, on a commercial scale, from dawsonite-bearing shale if analcime is present (Desborough, Mountjoy, and Frost, 1975).

Excess aluminum in oil shale, Parachute Creek Member, Green River Formation, Colorado

Sample current-image electron-microprobe and X-ray studies performed by G. A. Desborough on analcime and dawsonite-bearing oil shale from the Parachute Creek Member of the Green River Formation in the Piceance Creek basin, Colo., revealed an aluminum compound that occurred in grains 10 to 20 μm in diameter and contained no sodium, potassium, or silicon. The X-ray diffraction studies revealed no X-ray peaks that could be attributed to this compound, and thus the compound may be amorphous. This observation confirmed the presence of an apparently amorphous aluminum compound and verified calculations that indicated the presence of excess aluminum in bulk chemical analysis of some oil-shale samples.

Oil-shale resource, Piceance Creek basin, Colorado

An evaluation of the shale-oil resources in the rich oil shales of the Parachute Creek Member of the Green River Formation in the Piceance Creek basin, Colo., by C. W. Keighin indicated that, in beds 3.05 m or greater in thickness and yielding 7.25 kg or more of oil per tonne, there are 68 billion tonnes of oil in place. Of this amount, 47 billion tonnes are in beds that yield 8.7 kg or more per tonne. Resources calculated for beds yielding 10.15 kg/tonne and 11.6 kg/tonne are 25 billion tonnes and 11 billion tonnes, respectively.

It appeared that approximately 30 percent of the shale oil contained in beds 3.05 m or greater in thickness and yielding 7.25 kg or more of oil per tonne in the Piceance Creek basin was contained in the Mahogany zone.

NUCLEAR-FUELS RESOURCES

Uranium leaching in granitic rock

Rosholt and others (1973) suggested that the granite of the Granite Mountains, Wyo., had been depleted in uranium to depths as great as 50 m and that this uranium might have formed the ore deposits that surround the Granite Mountains. Preliminary results, obtained by J. S. Stuckless and I. T. Nkomo from shallow (3 m) drill holes and one deep (405 m) drill hole, support this hypothesis and suggest that the depth of uranium leaching is in excess of 400 m. The leached samples are generally fresh in appearance but are 50 to 80 percent depleted in uranium relative to the radiogenic daughter-product lead.

Core samples of the granite are highly variable in chemical and petrologic characteristics. The rock in the upper portion of the drill hole (approximately the upper 215 m) is typically hypidiomorphic-granular granite to quartz monzonite containing averages of 12 ppm U, 52 ppm Th, 54 ppm Pb, and 4.4 percent K. Within this portion, the uranium content ranges from 5 to 23 ppm. Samples from the lower portion of the drill hole (215 to 405 m) are xenomorphic-granular quartz-rich rocks that contain lesser amounts of uranium (7.0 ppm) and thorium (6.8 ppm) and more variable amounts of potassium (0.5 to 6.3 percent). Fracture zones, 0.5 to 3.0 m thick, in both portions of the core exhibit secondary enrichment of uranium (50 to 500 ppm).

Geologic controls of uranium depositional processes

Studies of the F. Brysch uranium mine, Falls City, Tex., by K. A. Dickinson and M. W. Sullivan suggested that the deposit was originally an unoxidized ore roll that was later oxidized. The host rock, the lower unit of the Deweesville Sandstone Member of the Whitsett Formation of the upper Eocene Jackson Group, is well-sorted medium-grained feldspathic sandstone deposited in a beach environment at or near a delta. A fluvial channel connected to this delta may have formed the passageway for uranium-bearing ground water and later for oxidizing water. The host sandstone contains much silicified wood that, before alteration, may have provided a reducing environment for the precipitation of the uranium. The ore minerals are meta-autunite and metatyuyamunite. The upper unit of the Deweesville in this mine comprises a lower part con-

taining corroded volcanic shards that appear to have partially altered directly to montmorillonite and an upper part lacking both montmorillonite and shards but containing small lathy clinoptilolite crystals in the interstices of the sandstone.

Studies by M. W. Green and C. T. Pierson revealed the geologic factors that controlled deposition of small uranium deposits in basal Dakota Sandstone of Early (?) and Late Cretaceous age in the Gallup area of New Mexico. The uranium was either dissolved from preexisting deposits in the Morrison Formation or leached from arkosic Morrison sediments. Uranium-bearing ground water from the Morrison entered the Dakota in areas where either the upper part of the Brushy Basin Member was permeable because of sandy facies or the Brushy Basin had been removed by erosion. A relatively large accumulation of carbonaceous material in the basal Dakota provided the reducing environment that precipitated the uranium.

Fluvial drainage patterns of Eocene age and their implications for uranium exploration

Paleocurrent maps of the Eocene Wind River Formation in the Wind River Basin, Wyo., by D. A. Seeland defined promising uranium-exploration target areas in which favorable lithologic conditions are likely to occur and in which the rocks were derived from the granitic core of the Granite Mountains. These targets ranked in decreasing order are (1) the lower few kilometres of the Eocene streams that drained northeastward from the Granite Mountains just south of their confluence with the Eocene Wind River, (2) the 40-km segment of the Eocene Wind River extending westward from near Powder River, and (3) the southeastern part of the Wind River Basin, where the Eocene Wind River Formation has a Granite Mountain source, but upstream from the area ranked first.

Crossbedding orientation measurements in the Eocene fluvial sandstones of the Wind River Basin were used to construct vector mean and moving average paleocurrent maps, which define the stream systems and source areas of the Eocene rocks of the basin. The Eocene "Wind River" flowed east-southeast across the northern part of the basin, left the basin near the present town of Powder River, and flowed eastward across the Casper arch into the Powder River Basin. Northeasterly trending streams carried coarse-grained arkosic sandstones in which the Shirley Basin and Gas Hills uranium deposits are found.

Formation rate of roll-type uranium deposits

Roll-type uranium deposits are commonly associated with large altered sandstone tongues that occupy areal extents of several tens of square kilometres. Calculations by H. C. Granger and C. G. Warren suggested that the alteration of most of these tongues probably took less than 1 m.y. and commonly must have occurred before the rocks were deeply buried or indurated.

The calculations are based on estimates that relate the flow rate (Darcy's law) to dissolved oxygen content (Henry's law) to ground water, diagenetic pyrite content of the host rock, and probable chemical reactions between the pyrite and the oxygen. In a typical example, ground water probably percolated through the rocks about 4,000 times as fast as the altered zone advanced. If 50 ppb U were extracted from the altering solutions, a moderately large uranium deposit could be formed in about 50,000 yr.

Uranium potential of Lower Cretaceous rocks, Colorado Plateau

Lower Cretaceous rocks in Colorado and Utah may have potential for uranium deposits because of their similarity to the major uranium-bearing formations of the Colorado Plateau. Studies by L. C. Craig indicated that the Lower Cretaceous Burro Canyon Formation consists of a sequence of alternating sandstone and mudstone that was derived in part from source areas south of the Four Corners area. The sediment was deposited in a fluvial system that trended northward in southwestern Colorado and adjacent Utah and eastward to northeastward in west-central Colorado. The subsurface extensions of two sandstone lobes in west-central Colorado along the southwestern margin of the Piceance Creek basin may have provided the proper geologic habitat for uranium deposition.

Uranium potential of Upper Cretaceous rocks, Crook County, Wyoming

The Fox Hills and overlying Lance Formations, which accumulated on a coastal plain during the final regression of the Cretaceous interior sea, are objects of increasing uranium-exploration activity. Studies by H. W. Dodge, Jr., and J. D. Powell indicated that the Fox Hills was deposited in marine delta-front and strand-plain environments and that the Lance was deposited in fluvial upper-deltaic-plain environments. The Fox Hills consists of 25 m of lenticular to tabular claystone, siltstone, and sandstone. The Lance contains a distributary channel facies and an interdistributary facies. The chan-

nel facies consists of fine-grained to very fine grained, partly calcareous sandstone; lag deposits containing dinosaur bones, claystone clasts, and wood fragments; and slump breccias in the larger channels. Large-scale trough crossbedding is common in the channels, and ripple structure is common in the upper parts of smaller channels. The channels are nearly straight, and the bases are convex downward in cross section. Transport directions in the channels are generally southeast. Organic-rich mudstone, clayey siltstone, and sandstone were deposited in the interdistributary areas of the Lance.

Epigenetic uranium deposits of intermediate grade have been found in the Fox Hills and Lance Formations. Reconnaissance radiometric surveys revealed several low-intensity anomalies ranging from 3 to 10 m in diameter in the lower part of the Lance. The uranium deposits may be related to local structural features and to natural gas deposits.

Uranium-bearing pegmatites in the Kettle River Range

Uranium-bearing pegmatites in the Kettle River Range, northern Ferry County, Wash., are concentrated in the wall rocks of gneissic granodiorite that is equivalent to the Cascade Granodiorite of Daly (1912). Geologic mapping by R. C. Pearson in the Togo Mountain quadrangle showed that most pegmatites lie within 2 km of the several granodiorite plutons. Only those near the largest pluton, mainly in the vicinity of Mount Leona, show evidence of having been prospected. No uranium minerals were observed during the mapping of the pegmatites near the granodiorite bodies in the northeastern part of the quadrangle (Independence Creek and north of Little Boulder Creek), but they may warrant further investigation.

The Midnite uranium mine, Stevens County, Washington

The Midnite mine in Stevens County, Wash., is one of only two mines in the United States currently producing uranium from discordant deposits in crystalline host rocks. According to J. T. Nash (USGS) and N. Lehrman (Dawn Mining Co.), the orebodies are in metamorphosed, steeply dipping Precambrian pelitic and calcareous rocks of a roof pendant adjacent to a Cretaceous porphyritic quartz monzonite pluton. Annual production is about 120,000 t of ore containing an average of 0.23 percent U_3O_8. Irregular orebodies as much as 75 m wide, 200 m long, and 50 m thick are found within 100 m of the pluton. Near-surface ore is oxidized, but ore at depth contains pitchblende, coffinite, and abundant pyrite and marcasite. The ore is in disseminations along foliation in replacements and stockwork fracture fillings. The richest ore is found in high-angle fault and shear zones and in stockworks of hornfels near irregular intrusive contacts. Ore deposition apparently was not stratigraphically controlled. The host rocks are graphitic phyllite and schist. Amphibolite sills and dacite dikes locally contain ore. Alteration of diopsidic bands to green montmorillonite is the only common ore-associated alteration noted. Background uranium values in the pluton are about 12 ppm, but these rocks are not strongly altered, and no veins or significant ore has been found there. A simple genetic link between the pluton and the orebodies is not apparent. Several processes of uranium emplacement, including some supergene enrichment, probably occurred in this mine.

Uranium- and coal-bearing Tertiary rocks

One of the most important coal-bearing areas in the Powder River Basin, if not in all of the United States, is the area surrounding and extending about 80 km south of Gillette, Wyo. Important uranium deposits are present in the southern and southwestern parts of the basin. Uranium and coal are present in the upper part of the Paleocene Fort Union Formation and the lower part of the Eocene Wasatch Formation. Low-grade uranium deposits are reported from carbonaceous beds in the lower part of the Upper Cretaceous Lance Formation north and east of Gillette. These conclusions are the result of continued regional mapping and study of subsurface data throughout large areas in the Powder River Basin of eastern Wyoming and adjoining parts of southeastern Montana by N. M. Denson and G. H. Horn (1975).

Uranium vein localized near old erosion surface

In the Cochetopa district, Saguache and Gunnison Counties, Colo., studies by J. C. Olson indicated that the principal uranium deposit in the district, at the Los Ochos mine, is localized near the old erosion surface on which Oligocene volcanic rocks were deposited. Contours drawn on this ancient surface show the position of the valley of the ancestral Cochetopa Creek, which flowed northward through the district, slightly east of its present position. The uranium vein is located along the Los Ochos fault near the point where it is crossed by the prevolcanic Cochetopa valley. This localization suggests the possibility that the intersection of the fault and the prevolcanic valley may have provided the conditions necessary to cause deposition of uranium from Ter-

tiary ground or from surface waters moving down the ancient surface on pre-Tertiary rocks.

Four varieties of thorite in Colorado pegmatite

Four rare-earth-rich varieties of thorite, characterized by different colors (brown, yellow, orange, and black), are present in narrow fracture fillings in the Seerie pegmatite near Pine, Colo., according to M. H. Staatz. The orange and black varieties are metamict; the brown and yellow varieties are not. The black, orange, and yellow varieties are commonly found together; the black variety forms a core surrounded first by orange and then by yellow. The black variety has 15 percent UO_3, the yellow and orange varieties have 7 percent UO_3, and the brown has only about 3 percent UO_3. The brown variety contains 5 percent Fe, about fifteen times as much as the other varieties. Rare-earth content of the four thorites ranges from 17 to 20 percent, more than has been reported from any other thorite. The rare earths in these minerals are also unusual in that they are principally of the yttrium group. Ytterbium is the commonest lanthanide in all four thorites.

A nuclear-track technique for uranium analysis of water

A nuclear-track technique for rountine sub-part-per-million uranium analysis of water was developed for use at the USGS reactor facility by G. W. Reimer. A small quantity of water, typically less than 1 ml, is placed into a similarly sized container. This procedure can be done in the field if desired. A fission-track detector is placed in the container, which is then sealed. The container is placed in a nuclear reactor and irradiated; the detector is removed and etched to develop the fission tracks that have resulted from the irradiation. Finally, the tracks recorded in the detector are counted by using a microscope. The number of tracks is related directly to uranium concentration. The method is rapid, requires only a small quantity of sample, and reduces the risk of sample contamination.

Thorium deposits, Wet Mountains, Colorado

Thorium deposits in the Mount Tyndall quadrangle and vicinity are found in carbonatite dikes, syenite dikes, barite veins, smoky quartz-barite veins, and iron-oxide-rich shear zones and fractures, according to T. J. Armbrustmacher. The carbonatite dikes, also commonly rich in rare-earth elements, are more abundant in the northern part of the quadrangle near the alkalic igneous complexes at McClure Mountain, Gem Park, and Democrat Creek.

GEOTHERMAL RESOURCES

Raft River geothermal area, Idaho

Extensive geophysical, geological, and hydrologic studies by the USGS during 1974 in the Raft River area of southern Idaho led to the siting of a 1,526-m exploratory well drilled by the Idaho National Engineering Laboratory (ERDA). Bottom-hole temperature is 147°C, slightly greater than the 135° to 145°C predicted by Mitchell and Young (1973) from SiO_2 and Na-K-Ca analyses of water from shallow wells. Artesian flow from the deep well exceeded 60 $l \cdot s^{-1}$ initially but has since decreased to about 20 $l \cdot s^{-1}$.

The Raft River valley lies at the northern margin of the Basin and Range province and is a north-trending late Cenozoic downwarp bounded by normal range-front faults on the western, southern, and eastern sides. Faulting within the basin along fault sets parallel to the basin margins continued into late Pleistocene time. Geologic studies by P. L. Williams and K. L. Pierce (unpub. data, 1975) showed that the geothermal anomaly near Bridge in the southern part of the valley is located along such a north-trending fault set where it intersects an east-northeast structure, probably a right-lateral fault, that passes through the Narrows of the Raft River and separates widely different structural styles in the southern Jim Sage Mountains west of the valley. The Raft River anomaly appears to be an example of fault-intersection control of hot-water movement.

Gravity, magnetic, refraction, seismic, resistivity, audiomagnetotelluric, self-potential, and telluric current surveys have been made in the Raft River area by D. R. Mabey, A. A. R. Zohdy, H. D. Ackerman, D. B. Hoover, D. B. Jackson, and J. E. O'Donnell. The geophysical data suggest that the maximum thickness of Cenozoic sedimentary and volcanic rock underlying the valley is about 2 km and that the valley is bounded by normal faults on the east and south and by a complex system of faults on the west. Large gravity, magnetic, and total-field resistivity highs within the valley immediately east of the Jim Sage Mountains reflect an igneous rock mass, at a relatively shallow depth, too old to relate directly to a geothermal system. The seismic interpretation divides the valley into four separate areas in which the Cenozoic rocks have distinctive seismic velocities. These areas appear to relate to known or inferred structures and to a suspected zone of shallow warm water. Resistivity anomalies reflect compositional variations in the Cenozoic rocks and variation in degree of induration and alteration. The resistivity

soundings show a 2 to 5-ohm-m resistivity unit with a thickness of 1 km underlying a large area of the valley, which may in part be indicative of hot water. Observed self-potential anomalies are believed to mark zones where warm water is ascending toward the surface.

The geological and geophysical investigations at the Raft River were supplemented by 4 core holes 83 to 433 m deep, drilled under the supervision of E. G. Crosthwaite. Data collected from these holes included cores, temperature logs, radioactive logs, electrical logs, caliper logs, depths to water, pressure heads, and information on fluid chemistry.

Late Cenozoic ring faulting and volcanism in the Coso geothermal area of California

The Coso Mountains of southeastern California are underlain principally by Mesozoic granitic rocks that are partly veneered by late Cenozoic volcanic rocks. In apparent decreasing age, the volcanic units include (1) widespread basaltic flows, mostly in the southeastern and central parts of the range, (2) dacitic flows and tuff capping ridges along the western side of the range, and (3) rhyolitic domes and flows and basaltic cones and flows in the south-central part of the range. Recent mapping by W. A. Duffield (1975) showed that all of these volcanic rocks are encompassed by an oval-shaped zone of late Cenozoic ring faulting that measures about 40 km east-west and 45 km north-south and defines a structural basin. Most of the Coso Mountains and a slice of the adjacent Sierra Nevada lie within this ring structure. The young rhyolites range in age from 960,000 to 40,000 yr (Lanphere and others, 1975) and, with associated active fumaroles, occupy a north-trending structural and topographic ridge about 18×10 km near the center of the basin. The ring structure and associated volcanic rocks suggest a large underlying magma chamber that has periodically erupted lava to the surface during the past few million years. Planned geophysical and seismic studies will search for any remaining magma to help assess the geothermal resources of the area.

Quaternary volcanism in the Clear Lake area, California

Geologic mapping of the Clear Lake volcanic field, Calif., by B. C. Hearn, Jr., J. M. Donnelly, and F. E. Gaff (unpub. data, 1975) has shown that faults are numerous and predominantly northeast and north-northwest. There is evidence for recent strike-slip movement on one north-northwest zone. Potassium-argon age, magnetic polarities, and C-14 dates from the complex volcanic sequence range from 2.5 m.y. to about 15,000 yr. Much of the field is younger than about 1.1 m.y., and the central part is younger than 0.55 m.y. The youngest silicic eruption is 0.9 m.y. Geophysical evidence suggests that there is a partially fluid magma chamber at depth beneath the volcanic field. Repeated silicic volcanism, lack of welded tuffs, and lack of large-scale caldera collapse suggest that the volcanic system is in an early evolutionary stage. According to the model of Smith and Shaw (1973), the size and youth of the Clear Lake system infer that the volcanic field and its surroundings have considerable geothermal potential.

Youthful volcanism in the San Francisco volcanic field, Arizona

Geologic mapping by E. W. Wolfe, G. E. Ulrich, R. B. Moore, and R. F. Holm, with K-Ar dating by E. H. McKee (USGS) and P. E. Damon (Univ. of Arizona), showed that very young silicic rocks are present in the eastern part of the San Francisco volcanic field. Among the youngest are obsidian in Doyle Saddle on San Francisco Mountain (0.68±0.01 m.y.), the Mount Elden dacite dome (0.55±0.03 and 0.56±3 m.y.), the Sugarloaf rhyolite dome (0.21±0.02 m.y. and 0.13±0.1 m.y.), the O'Leary Peak rhyodacite (0.23±0.04 and 0.14±0.07 m.y.), and the Robinson rhyodacite dome (0.27±0.2 and 0.15±0.1 m.y.). Even younger ages (50,000±14,000 yr and 46,000±46,000 yr) have been determined for basaltic andesites from vents with small rhyodacite plugs. These occurrences suggest that an area including San Francisco Mountain and extending eastward about 32 km from the mountain ought to be a prime target area for geophysical detection of intrusive bodies, anomalous seismicity, and geothermal energy. This area also contains most of the known young basaltic volcanic rocks, including the 910-yr-old Sunset Crater.

Gravity mapping by J. D. Hendricks showed an arcuate activity low west of the San Francisco Mountain area. The gravity low, in an area where silicic volcanic rocks are concentrated, suggests the possibility of a low-density silicic intrusion within the crust in this area.

Geothermal significance of rhyolite age progression in Oregon

Late Cenozoic rhyolitic domes, vent complexes, and associated ash-flow tuffs in southeastern Oregon, which are similar in many respects to silicic volcanic complexes that are associated with most of the world's electric-power-producing geothermal fields, were studied by N. S. MacLeod and E. H. McKee. Most of the 150 domes occur in two diffuse 250-km-long belts that trend N. 75° W. The northern belt, in the High Lava Plains province, extends from New-

berry Volcano near the Cascade Range to beyond Harney Basin; the southern belt, in the northern part of the Basin and Range province, extends from Yamsey Mountain, 80 km south of Newberry, to or beyond Beatys Butte near Catlow Valley. A few domes occur between the two belts, particularly in the western part of the area. The domes show a remarkably regular increase in age towards the east, on the basis of 38 K-Ar dates, and thus an earlier suggestion by G. W. Walker is confirmed. The youngest rhyolites are associated with Newberry Volcano on the western end of the northern belt, where many obsidian flows and ash falls and flows are less than 7,000 yr old. The dome at McKay Butte, on Newberry's western flank, is 0.6 m.y.; China Hat, on the eastern flank, is 0.8 m.y. Progressing eastward, the dome at East Butte is 0.9 m.y.; Quartz Mountain is 1 m.y.; Long Butte is 2.3 m.y.; Squaw Ridge is 3.6 m.y.; Fredericks Butte is 3.9 m.y.; Cougar Mountain is 4.3 m.y.; and Glass Butte is 4.9 m.y. Twelve dated domes farther east are progressively older to Duck Butte, which is 10 m.y. The youngest dated dome in the southern belt, at its western end near Yamsey Mountain, is 4.7 m.y. Progressing to the east and southeast, the dome at Partin Butte is 5.0 m.y.; Black Hills is 5.4 m.y.; and Hager Mountain is 5.9 m.y. Seven dated domes farther east progress in age to 10.4 m.y. at Beatys Butte. Dated domes between the two belts include one near Stams Mountain, which is 4.5 m.y., one near Bald Mountain, which is 5.1 m.y., and three near Horse Mountain, which range from 6.7 to 6.9 m.y. The regularity of the age increase towards the east permits the construction of isochrons that can be used to predict the age of most undated domes to within about 0.5 m.y. Available K-Ar dates on extensive ash-flow tuff sheets indicate that their probable vent areas also fit this age progression. Graphs of areal extent of domes versus age and of number of domes versus age both suggest a major period of rhyolitic volcanism about 7 m.y. ago, followed by a progressive decline that extends to the late Quaternary. The only domes that are less than 2 m.y. occur in the immediate vicinity of Newberry Volcano. Geothermal areas east of the Cascade Range that have cooling silicic intrusive bodies as their heat source thus are probable only near Newberry.

Geothermal reconnaissance of young volcanic areas around the Colorado Plateau

Age and composition data on upper Cenozoic volcanic rocks were collected by P. W. Lipman along the margins of the Colorado Plateau, in the volcano-tectonic setting where a significant geothermal resource is currently being developed in the Jemez volcanic field of northern New Mexico. Upper Cenozoic silicic rocks that might indicate the presence of sizable shallow magma chambers seem to occur mainly in the White Mountains of Arizona and in the Mount Taylor and Taos Plateau volcanic fields of New Mexico, although some do occur in the Jemez Mountains and the San Francisco Mountain area of Arizona as well; these latter areas are currently being studied in detail by other USGS geothermal projects. Stratigraphic and age relations of young rocks are poorly known in the two New Mexico volcanic fields, and so brief field reconnaissance studies have been supplemented by K-Ar dating by H. H. Mehnert.

In the Mount Taylor area, volcanism began about 3 m.y. ago with the widespread eruption of previously unrecognized lava flows and domes of viscous trachyte that extend from the site of the overlying Mount Taylor cone northeastward for at least 30 km. The Mount Taylor stratovolcano was constructed of rocks ranging from alkali andesite to rhyolite between about 3 and 2 m.y. ago, concurrent with the eruption of silicic alkalic basalt around its flanks. The youngest basalt capping adjacent high mesas is about 1.5 m.y. old.

The Taos Plateau volcanic field consists of a cluster of at least 25 stratovolcanoes and shields, ranging in composition from olivine andesite to silicic rhyolite, that are concentrated mostly within an area about 40 km in diameter within the Rio Grande graben in northern New Mexico. These volcanoes are all morphologically young, and one rhyolite lava dome is about 4 m.y. old. The Taos Plateau volcanoes were partly buried by flows of tholeiitic and alkalic basalt as young as about 2 m.y. This young volcanism is more voluminous and compositionally diverse than any other within the Rio Grande graben, with the exception of the Jemez volcanic field. The clustered, compositionally diverse volcanoes of the Taos Plateau field may have resembled the Jemez field prior to the ash-flow eruption and collapse of the Valles caldera, but any large, shallow body of silicic magma underlying the Taos Plateau probably had largely crystallized by the time the basalts erupted from within the volcanic cluster.

Fault-controlled hot-spring systems of central Colorado

Several hot springs lie in the Buena Vista and Poncha Springs quadrangles in central Colorado, mapped by G. R. Scott. Poncha, Mount Princeton, Hortense, and Cottonwood Hot Springs lie along

intensely brecciated fault zones bordering the Upper Arkansas Valley graben segment of the Rio Grande Trough. These fault zones have been recurrently active at least since early Miocene time and apparently project to great depth. Zeolitized rock locally extends thousands of metres out into the footwalls of some of the faults and probably formed in the roots of hydrothermal systems at an early stage of the faulting. The modern hot springs apparently lack an adequate recent source for magnetic heat and thus derive their heat from deep circulation of water along the faults ystems.

Exploration of geothermal systems by aerial thermal infrared surveys

Although thermal infrared surveys provide a direct measure of surface heating, the variations in surface temperature due to geologic-topographic factors tend to mask the effects of geothermal heating. A thermal model was used by Kenneth Watson (1974) to demonstrate that measurements of the mean diurnal temperature, together with reflectance measurements and slope information, can be used to map the geothermal flux. Theoretical calculations show that the error estimate of the mean diurnal temperature (V_{dc}) falls off rapidly with increasing sample measurements per diurnal cycle (650 HFU at 1 sample/cycle and 75 HFU at 3 samples/cycle).

The thermal model was also used to examine the optimum times in the diurnal cycle at which to obtain an estimate of V_{dc}. A thermal image and a reflectance image of the Raft River area in Idaho acquired at the optimum time for 1 sample/cycle show the presence of warm thermal anomalies, which do not coincide with changes in the reflectance image. Probe measurements in the vicinity of this area confirm the presence of such an anomaly.

Reservoir engineering of vapor-dominated geothermal systems

Manuel Nathenson calculated various properties for the vapor-dominated reservoir system of Larderello, Italy, by using available published data. Measurements made to date on flowing steam wells have almost always been taken at the wellhead. To better understand the reservoir mechanics, these wellhead quantities were converted to values at the well bottom. In two sample wells, large variations in wellhead temperature with flow at a particular time are shown to correspond to nearly constant temperatures at the well bottoms. For a third well, trends in wellhead values correspond to similar trends at the bottom of the well. Wellhead temperatures in flowing wells measured over a period of years have also been converted to equivalent bottom temperatures. These calculated temperatures can increase, decrease, or remain nearly constant, depending on the local environment of the particular well.

The initial fluid mass in place in the northeastern zone of Larderello has been estimated by using data on shut-in pressures and total mass production. The reservoir thickness needed to store this mass of fluid has been calculated as a function of porosity and initial volume fraction of water in average pores. The thickness is 19 km if it is assumed that there is 5 percent porosity with steam as the only fluid to 832 m and 20 percent porosity and 10 percent pore volume to be liquid water.

Annotated bibliography of volumetric properties of geothermal brine

A complete annotated bibliography of the volumetric properties of geothermal brines was compiled from the 1928–1974 literature by R. W. Potter III, D. R. Shaw, and J. L. Haas, Jr. (1975). This compilation contains data useful in designing energy extraction systems for geothermal brine fields. Laboratory experiments to fill the many data gaps are presently being undertaken by Potter.

Ground movement in geothermal areas of California and Idaho

B. E. Lofgren reported that survey networks of vertical and horizontal control are now monitoring possible ground movement in The Geysers and Imperial Valley, Calif., and the Raft River valley, Idaho, geothermal areas. During the summer of 1975, similar nets were established in Long Valley, Calif. Also, vertical extensometers and tiltmeters are being installed at selected sites in Imperial Valley to detect tectonic trends prior to geothermal development.

Three significant occurrences measured by the monitoring program prior to geothermal development are:

1. A northward tilt in Imperial Valley of about 13 cm in the 85 km from Calexico on the north to the county line north of Niland from spring 1972 to spring 1974.
2. An apparent 5 mm/yr of right-lateral ground movement along a northwest-trending fault zone in the Buttes area, Imperial Valley.
3. As much as 0.8 m of land subsidence in an area of heavy ground-water pumping north of Malta in the Raft River valley.

REGIONAL GEOLOGIC INVESTIGATIONS

NEW ENGLAND

Geologic quadrangle mapping at 1:24,000 by the USGS in cooperation with the States of Connecticut and Massachusetts progressed satisfactorily in 1974. More than 56 percent of the bedrock and 49 percent of the surficial geologic quadrangle mapping of Massachusetts has been completed. In Connecticut, 97 percent of the bedrock and 82 percent of the surficial geologic quadrangle mapping has been completed. In addition, substantial progress was made toward compilation of revised intermediate-scale (1:125,000) bedrock geologic maps of both States. These compilations have been facilitated by the use of moderately new remote-sensing data from aeromagnetic, airborne radiometric, and gravity surveys, plus side-looking radar imagery. These data, combined with published and open-filed geologic quadrangles, yield an overall regional structural synthesis for this complex metamorphic terrane. Geophysical data in offshore areas have indicated major structural trends as well as the nature of unconsolidated sediments. The USGS. is presently engaged in cooperative programs with the States of Massachusetts, Connecticut, and New Hampshire. Results of last year's research, summarized below, show a concentration of effort in Massachusetts, the State with the greatest financial participation.

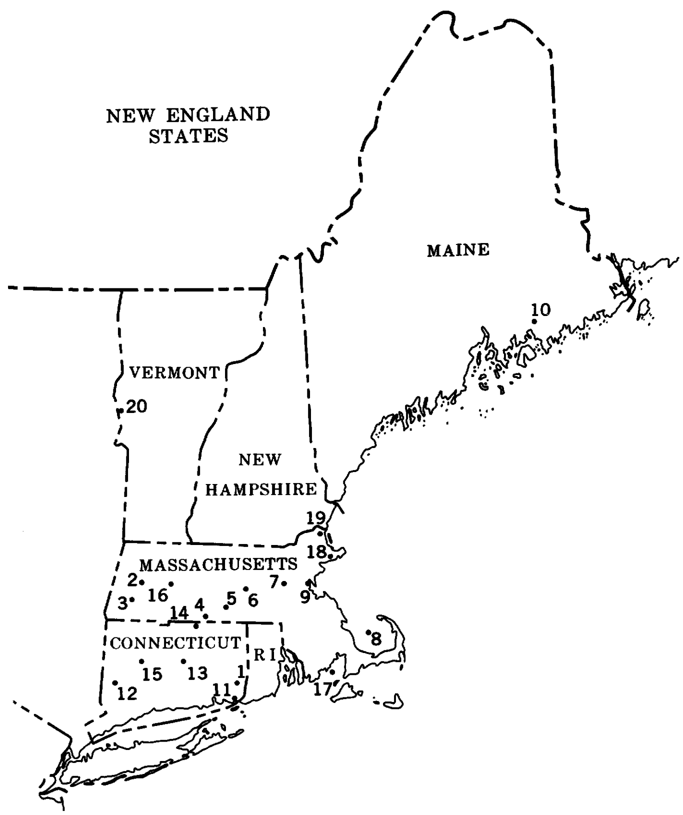
STRUCTURAL AND STRATIGRAPHIC STUDIES

Structural pattern in southern New England

A summary of geologic interpretations of geophysical, topographic, radar, and LANDSAT lineaments in southern New England by P. J. Barosh showed that the pervasive faulting known in the Triassic rocks of the southern Connecticut River valley is also present in the older basement rocks. Lineaments indicative of fault extensions and probable faults, along with mapped faults, show that southern New England is cut by several important northeast-trending fault zones. Northerly trending faults lie between these zones in places and cut some of the northeast-trending faults. Several important easterly trending fault zones are also present, mainly in southeastern New England. These three trends appear to have formed contemporaneously because they cut one another. All three are cut by prominent northwest-trending faults with little displacement. Several northeast-trending faults have apparent right-lateral displacement.

Base of the Quinebaug Formation, southeastern Connecticut

Layered metavolcanic rocks as much as 800 m thick structurally below and in the Honey Hill-Lake Char fault zone in the northern Old Mystic quadrangle and southeastern Jewett City quadrangle (loc. 1, index map) lie conformably on quartzite and schist of the Plainfield Formation. Some of these metavolcanic rocks are similar to those of the Quine-



baug Formation lying in and above the Honey Hill fault zone. No clear stratigraphic boundary between the two metavolcanic sequences can be readily discerned through the cataclasis. However, the metavolcanic rocks of the lower plate seem to be more quartzose and contain layers of mafic-poor felsic rock not found in the metavolcanic rocks of the upper plate except in the fault zone. On this basis, metavolcanic rocks above the fault zone are being mapped by H. R. Dixon and Richard Goldsmith as Quinebaug Formation, whereas those below the fault zone are being mapped as a separate metavolcanic unit above the Plainfield Formation. It is possible that the metavolcanic rocks on both sides of the fault zone represent one continuous sequence in which the mafic-poor felsic layers occur only in the lower part.

If so, little displacement need have occurred along the Honey Hill-Lake Char fault system, as Lundgren and Ebblin (1972) suggested. However, the situation is perhaps analogous to that along strike in eastern Massachusetts, where K. G. Bell (1973, p. 28) described two metavolcanic units in juxtaposition. He postulates an unconformity between metavolcanic rocks of the Blackstone Series in a terrane extensively intruded by Dedham Granodiorite, and metavolcanic rocks of the overlying Marlboro and Nashoba Formations in a terrane in which there is no Dedham Granodiorite.

Three periods of cataclastic deformation in southeastern Connecticut

Three periods of cataclastic deformation were demonstrated by H. R. Dixon and Richard Goldsmith in the area of the Preston Gabbro in the Jewett City and Old Mystic quadrangles (loc. 1). The earliest deformation involved regional metamorphism and subsequent early cataclasis of the Quinebaug Formation and overlying metasedimentary rocks, followed by intrusion of the gabbro, as shown by intrusive relationships. The southern end of the gabbro near Ayer Hill and Prentice Mountain is a composite mass consisting of a core of hornblende gabbro surrounded by hornblende diorite and with discontinuous masses of quartz diorite, locally trondhjemite. These rocks appear to be comagmatic. The quartz diorite phase, in places showing little or no foliation or cataclasis, cuts and encloses fine-grained mylonitic rocks of the Quinebaug Formation. On the northwestern and southwestern sides the gabbro or its trondhjemite differentiate, with a primary igneous fabric, crosscuts layering and foliation of the Quinebaug and contains inclusions of gneissic or mylonitic Quinebaug.

A second stage of cataclastic deformation affected the entire gabbro body and surrounding rocks. The most intense deformation was along the eastern and southern sides of the gabbro, where the gabbro and underlying rocks of the Plainfield Formation and alaskite gneisses of the Sterling Plutonic Group are converted to mylonite in a belt a few tens of metres thick. These mylonites are along the southern limit of the Lake Char fault and the eastern limit of the Honey Hill fault, where the two faults join. All rocks are cut by a north-south-trending system of normal faults accompanied by brecciation, hydrothermal alteration, and silicification. These faults belong to the third stage of deformation and are part of the Lantern Hill fault system of probable Triassic age.

Radiometric chronology and major structures of the Berkshire massif, western Massachusetts

Three groups of rocks, interlayered with the Hoosac Formation (Lower? Cambrian or older) along the east margin of the Berkshire massif (loc. 2), have been dated by Rb-Sr whole-rock techniques. Cataclased foliated granite yielded an age of 894 ± 58 m.y. A suite of metavolcanic or metaigneous rocks yielded an age of 1.11 ± 31 b.y. Weakly foliated granites, interpreted to be in fault contact with the Hoosac, yielded an age of 605 ± 50 m.y. (D. G. Brookins and S. A. Norton, 1975). These results suggested to Norton the following (partial) history of the rocks at the east margin of the Berkshire massif:

- Volcanic rocks deposited, 1.1 b.y.
- Grenville orogeny plus intrusion of granite gneiss, 0.9 b.y.
- Intrusion of granites, 0.61 b.y.
- Deposition of Hoosac Formation and younger rocks, 0.6 to 0.44 b.y.
- Tectonic intercalation of Precambrian rocks with Paleozoic metasedimentary rocks, probably during Taconic time.

A 30-km-long east-west cross section of the Berkshire massif along lat 42°15′ N. (loc. 3), extending from miogeosynclinal rocks of the Stockbridge Valley on the west to the overthrust eugeosynclinal Hoosac and younger sequence on the east, is complete. On the basis of the results of this study, N. M. Ratcliffe suggested that the Precambrian massif at its widest part is composed of nested low-angle overthrusts that extend eastward in complexly deformed synclinal and anticlinal structures. The youngest and structurally highest thrust slices are confined to the central portion of the massif. The geometry of these slices indicates that the major structure of the massif is broadly synclinal rather than anticlinal, and thus the term Berkshire anticlinorium is mis-

leading. Structural analysis of minor drag folds from zones of blastomylonite indicates slip line azimuths from 70° to 160°. The Beartown Mountain slice overrides the Paleozoic miogeosynclinal sequence for a minimum distance of 21 km, and a higher slice, the October Mountain slice, in turn overrides the Beartown Mountain slice for a minimum distance of 15 km in the slip direction. A minimum of 36 km of tectonic foreshortening is suggested for the rocks of the Berkshire massif. Later folding of the thrusts may account for an additional 10 km of shortening. The cross section indicates that the outcrop width of massif rocks may have been in excess of 45 km prior to Taconic orogenesis. The rocks may have been situated at least 21 km farther east than their present location with respect to the underlying miogeosynclinal sequence. A restored position places the rocks above the crest of the regional positive Bouguer anomaly.

Major structures east of the Monson Gneiss, central Massachusetts

A northeast- and north-trending 1.6-km-wide syncline or synclinorium, composed chiefly of layered rocks of the Mount Pisgah Formation, was mapped by J. D. Peper east of and adjacent to the Monson Gneiss in the Palmer quadrangle (loc. 4). Evidence for overturning is based on a few relict sedimentary structures that indicate tops of beds to the east. The Bone Mill Brook fault, a major regional fault associated with cataclastic rocks along the eastern edge of the Monson Gneiss in the Stafford Springs, Monson, and Palmer quadrangles, truncates the axis of the syncline near the border of the Monson and Palmer quadrangles. A discordant northward-widening body of foliated porphyritic quartz monzonite invades the east limb of the syncline and invades and obliterates a north-trending anticline in the eastern and northeastern parts of the Palmer quadrangle.

Lithostratigraphic sequence in East Brookfield quadrangle, Massachusetts

Recent mapping by J. S. Pomeroy demonstrated that the subdivision of a thick sequence of high-grade metamorphic rocks in northeastern Connecticut (Peper, Pease, and Seiders, 1975) can be extended northward into the East Brookfield quadrangle (loc. 5). A sequence of mostly gray to less common, slightly rusty weathering felsic gneiss is the dominant rock type in the eastern part of the quadrangle. Thin units of sulfidic schist occur locally throughout this part of the section. Terrigenous sands and silts with minor euxenic muds and silts were the probable original sediments. Overlying these rocks to the west are mappable units of roughly equal proportions of rusty-weathering gneiss/sulfidic schist and gray-weathering felsic gneiss. The latter sequence represents an assortment of euxenic muds and silts with influxes of terrigenous and possible volcaniclastic debris. Rare occurences of relict graded bedding in gray garnetiferous gneiss indicate that the section is right side up.

Folded graded beds in the Worcester North quadrangle

A gray phyllite to mica schist unit with prominent arenaceous graded beds crops out in the central part of the Worcester North quadrangle (loc. 6). This unit contains graded beds similar to those reported by Peck (1972) in the Clinton quadrangle and interpreted by him as a metaturbidite. According to J. C. Hepburn, bedding reversals observed in large exposures along Interstate 290 indicate a series of isoclinal folds plunging moderately to the north-northwest with amplitudes on the order of 100 m.

Deformation in rocks of the Concord-Framingham-Natick area, eastern Massachusetts

Rocks in the Concord-Framingham-Natick area (loc. 7) were deformed during three periods of deformation, according to A. E. Nelson. During the first period, metamorphic schistosity (S_1) formed in the upper Cambrian to lower Paleozoic(?) rocks in response to ductile deformation that occurred in the early stage of regional metamorphism. Near the close of metamorphism, minor folds developed as initial structures of the second deformation. As the second deformation period continued, regional north-to northeast-trending folds formed, schistosity (S_1) was folded, and a slip cleavage (S_2) developed locally. Cataclastic foliation (S_x) associated with deep-seated faulting was formed in the rocks during a long interval. The third (Alleghenian) deformation period folded and faulted the Carboniferous rocks of the Boston Basin. At this time a cleavage (S_3) also formed in some Carboniferous rocks, but this cleavage has not been observed in the older rocks west of the Boston Basin.

Basement structure beneath Cape Cod Bay, Massachusetts

A basement structure contour map of Cape Cod Bay (loc. 8) compiled by R. N. Oldale and C. J. O'Hara showed a prominent lineament trending northeast from a point just north of Cape Cod Canal to a point just south of Provincetown. This lineament, made up of a number of basement lows, may represent a fault boundary separating strata of Triassic or Jurassic age to the south from igneous

and metamorphic rocks of pre-Triassic age to the north.

Inferred post-Tertiary history of Cape Cod Bay

Interpretation of seismic profiles by R. N. Oldale and C. J. O'Hara suggested the following geologic history for Cape Cod Bay. During Tertiary time the area underwent deposition and erosion similar to those of the unglaciated Atlantic Coastal Plain. Toward the end of Tertiary time, erosion removed much of the coastal plain strata, exposing basement rocks and producing an extensive drainage system. This surface is deeply buried by glacial drift deposited in large part during the advance and retreat of the last ice sheet. Fluvial erosion of the drift followed ice retreat as sea level rose toward its present level. As the Holocene transgression proceeded, drowned valleys became sites of estuarine deposition. Barrier beaches and lagoons developed locally. These beaches, now submerged to depths of 30 m or more, constitute a significant source of deposits of sand and gravel. Most recently, beach and bar deposits are forming in shallow water, and silt and clay are being deposited in deep water.

Volcanic sediments in the Boston Basin

Study of the rocks of the Boston Basin (loc. 9) by C. A. Kaye showed that much of the sediment is volcanically derived from fine- and coarse-grained pyroclastics, most of which were somewhat reworked and water deposited. The ashy tuffs have been traditionally classified as argillites, and the reworked, coarser material as conglomerate and tillite. At least three important intervals of eruption are recognized; the first two were dominantly andesitic, and the third was rhyolitic but with some mafic lavas. Two cones have been identified: a very large stratovolcano that centers on Mattapan and a small andesitic cone with evidence of hydrothermal (fumerolic) alteration. Both cones were involved in the deformation of the basin and are lying on their sides.

Intrusion of Lucerne pluton, Hancock County, Maine

The Lucerne pluton (loc. 10) moved laterally during intrusion, according to studies by D. R. Wones. Mylonite zones subparallel to the western edge and drag folds found in the metamorphosed Ellsworth Schist on the eastern edge of the pluton both imply motion from the south toward the northeast. Gravity studies by J. H. Sweeney (SUNY, Buffalo) indicated that the Lucerne pluton is thicker toward the south. A model of a rising magma flowing laterally to the northeast explains the shape of the pluton, its observed internal deformation, and the deformation of the intruded metasediments.

QUATERNARY GEOLOGY

Recessional moraines in southeastern Connecticut

Review by Richard Goldsmith (USGS) of mapping done in 1962 by J. W. Gaffney (then a student at the Univ. of Massachusetts) in the Old Mystic quadrangle (loc. 11), New London County, Conn., clearly confirmed the continuity of a set of minor recessional moraines that extend from Long Island Sound west of New London through the Stonington area into Rhode Island. The two moraines lie 13 km and 20 km, respectively, north of and parallel to the terminal Charlestown-Harbor Hill moraine. The northern moraine (Ledyard moraine) can be traced northwestward as a positive feature across the Old Mystic quadrangle from the western edge to the northeastern corner. The southern moraine, called the Rocky Hollow moraine by Gaffney, extends as a line of patches of ablation till, till ridges, and ice-contact deposits of sand and gravel from near Old Mystic to about 1 km south of North Stonington village. The Rocky Hollow moraine is alined with two closely spaced moraines in the Niantic area to the southwest and with morainic features mapped by J. P. Schafer in the central Ashaway quadrangle to the east. Schafer, in reconnaissance, has traced this moraine for about 77 km from the Niantic area into south-central Rhode Island (Schafer and Hartshorn, 1965). The Ledyard moraine has not been recognized in Rhode Island.

The moraines consist of loose bouldery till in places, with minor sand and gravel, usually showing hummocky topography; accumulations in a few places of boulders piled on one another without interstitial fine material; low linear ridges of compact till without exceptional boulder accumulations; and ice-contact deposits of sand and gravel, locally with flowtill. The low linear ridges are alined with other morainic features and lie at an angle to the trend of bedrock units. The morainic deposits lie along a somewhat sinuous, usually single line, but with a generally uniform east-northeast trend. The Ledyard moraine, however, splits into two parallel segments east and north of Lantern Hill. Boulder accumulations of stacked and piled boulders so spectacularly displayed at a few places, particularly along the Ledyard moraine, are considered to have formed where accumulations of bouldery till at the active ice-stagnant ice interface were washed by local ephemeral melt-water streams. On the tops of some high rocky ridges where outcrops are abundant, the moraine is

identified by a greater number of dispersed erratics than is usually found on such sites or by a low linear ridge of till without bedrock outcrops. Heads of outwash are more or less alined along the moraines, with some, usually fragmentary, coarse- to fine-textured ice-contact deposits of sand and gravel lying north of the line of the moraine. This outwash is considered to have been deposited by streams draining the zone of stagnant ice lying between the former active-ice interface and a new interface situated to the north. Gaffney describes ice-shove features in gravel deposits in the moraines and suggests that the moraines represent slight readvances rather than mere stillstands during ice retreat. Such readvances are, however, probably, of little significance. One would not expect an interface of live ice with dead ice to remain completely static in position.

Four levels of glacial Lake Danbury, southwestern Connecticut

Mapping by W. B. Thompson showed that deglaciation of the Danbury-New Milford area (loc. 12) resulted in the formation of glacial Lake Danbury, which occupied the Still River valley and part of the Housatonic River valley. Retreat of the ice front opened successively lower spillways and resulted in four lake levels. Glacial lakes also occupied the Danbury Fairgrounds area and probably the Lake Candlewood valley.

Triassic rock-derived drift east of the border fault, central Connecticut

The restriction of Triassic rocks to the northwest side of the border fault, which traverses the Glastonbury quadrangle (loc. 13), provides the basis for some estimates of drift transport by continental glacier ice and melt-water streams, according to surficial mapping by W. H. Langer, Reddish-brown till, composed primarily of material derived from Triassic sedimentary rocks, is common only within 2 km southeast of the border fault, although local deposits of reddish-brown till have been mapped as far as 6 km southeast of the fault. Stratified drift deposits, however, include significant amounts of Triassic material throughout the quadrangle, and material derived from Triassic rocks has been reported earlier by D. W. O'Leary (unpub. data, 1974) as far as 16 km southeast of the border fault in the Salmon River valley in the Moodus quadrangle, Connecticut.

Preglacial bedrock weathering and pre-Wisconsinan weathering of lower till, central and western Connecticut

Within the eastern Triassic border fault zone in Somers, Conn. (loc. 14), a 3-m section of severely weathered rock was excavated this summer in a large borrow pit on the southeastern slope of an 18-m-high ice-streamlined bedrock hill. The weathered rock is highly jointed breccia. Large pockets, up to 1 m in diameter, are completely kaolinized, containing fine-grained quartz masses up to 13 cm in diameter. Many joint surfaces are partly coated with a soft pink mineral (montmorillonite?) and (or) small semihedral to euhedral quartz crystals. C. T. Hildreth found that rock exposed by excavation on the northwestern side of the hill is fresh, and unweathered bedrock caps the hill. Apparently, the severe weathering is preglacial, and this small area survived glacial scouring because of its sheltered position in the lee of the bedrock hill. The feature is a large-scale example of crag-and-tail morphology.

Preglacially weathered marble from the Inwood Limestone, near Danbury, makes up a large portion of clasts in both the upper and the lower till (Schafer and Hartshorn, 1965), according to W. B. Thompson. The upper (Wisconsinan) till has a total carbonate content of 50 percent at one locality. Carbonate minerals have been leached from most exposures of lower till.

Weathering effects in the oxidized zone of the lower till at Thomaston Dam, Conn. (loc. 15), have been studied by B. D. Stone, using X-ray and thin section techniques. Illite shows increasing expansion by hydration upward through this zone, and garnets are dissolved and coated by iron oxide rims. Values of pH are as low as 5.5 in the oxidized zone but are as high as 7 or greater in fresh till. These results suggest that the altered zone may be the base of a soil profile that predated classical Wisconsinan glaciation. Correlation with Midwest till weathering sequences is precluded because of the noncalcareous nature of the lower till at Thomaston Dam and because of truncation by the last ice sheet.

Active-ice deglaciation of the Triassic Lowland, Massachusetts

Three types of evidence indicated deglaciation of the western side of the Triassic Lowland, central Massachusetts (loc. 16), by an active valley ice lobe, according to F. D. Larsen. The evidence is found in the Easthampton quadrangle along the north-northeast-trending contact of crystalline rocks of the New England Upland on the west and reddish-brown Triassic rocks on the east.

The stratigraphic evidence consists of reddish-brown till overlying grayish-brown till along the North Branch of the Manhan River 1.2 km southeast of Loudville, 0.5 km east of the crystalline-Triassic contact. The older grayish-brown till is inferred to have been derived from crystalline rocks and deposited during the glacial maximum by ice

that moved south into the Triassic Lowland from the New England Upland. The younger reddish-brown till was derived from Triassic rocks and was deposited at the southwestern edge of an active valley ice lobe just prior to ice retreat. Southwestern ice movement is indicated by the reddish-brown color of the till and southwest-trending striations.

Striations trending S. 75° W. at Loudville and S. 52° W. at a locality 3.5 km S. 20° E. of Loudville indicate a radial movement of ice in the southwestern part of the Easthampton quadrangle. These striations and those in the northern part of the Mount Tom quadrangle to the south form a distinct lobate pattern that extends across the lowland from Loudville to Mount Tom.

In addition, erratics derived from the Triassic Lowland have been transported west of, and higher than, the nearest Triassic rocks at the crystalline-Triassic contact on the southeastern slope of Pomeroy Mountain. This occurrence is similar to the 2- to 3-km-wide belt of erratics derived from Triassic rocks that lie west of the crystalline-Triassic contact in the Southwick quadrangle, Massachusetts-Connecticut (Schnabel, 1971).

Quaternary stratigraphy, Buzzards Bay, Massachusetts, determined from seismic reflection

From a high-resolution seismic reflection survey, J. M. Robb distinguished four sedimentary units underlying Buzzards Bay, Mass. (loc. 17). He inferred that nearly ubiquitous Holocene marine muds overlie probable glacial outwash deposits, which in turn overlie well-stratified sediments filling valleys cut into probable glacial till. Some of the valleys extend from valleys cut into bedrock that crops out along the northwestern side of the bay.

Glaciomarine deposits in northeastern Massachusetts

Glacial outwash graded to a marine baselevel in the Marblehead North quadrangle (loc. 18) is not found higher than 17 m above present mean sea level, as maps completed by M. J. Carnevale showed. To the north, work in the Merrimack River Valley near Newburyport (loc. 19) by A. F. Shride showed large ice-contact glaciomarine deltas graded to an upper marine limit of 27 to 30 m above present sea level. A few maximum marine strandline features such as wave-cut cliffs and berms occur at or just above the 100-foot (30 m) contour. In the same area, extensive sand plains at the 50-foot (15 m) contour surface apparently represent extensive erosion and deposition on grade with a lower, younger marine baselevel. These evaluations provide a more complete picture of postglacial crustal rebound along the New England coast.

Distribution of lacustrine and marine sediments in southern Lake Champlain

An EG&G Uniboom system was used to profile 205 km of track between Ticonderoga Bay and Split Rock Point, N.Y. (loc. 20). Total sediment thickness is least (10 m) south of the Crown Point Bridge and greatest (165 m) between Barber Point and Split Rock Point, N.Y. Several prominent acoustic reflectors appear to be the same as those reported to the north by Chase and Hunt (1972) and include the approximate boundaries between Lake Vermont, Champlain Sea, and Lake Champlain sediments. Those presently inferred to be of Lake Vermont age range from 0 to 125 m thick, and those of more recent age from 0 to 60 m thick. A prominent terrace at 0 to 3 m above sea level (26 to 29 m below present lake level) probably is due to erosion during a low lake level stand during Champlain Sea or early Lake Champlain time.

APPALACHIAN HIGHLANDS AND THE COASTAL PLAINS

Conodont color alteration, an index to diagenesis of organic matter

According to A. G. Epstein, J. B. Epstein, and L. D. Harris (1974), mapping of conodont color alteration by geologic system throughout the Appalachian basin and laboratory experiments inducing color alteration showed that (1) the sequence of color change from pale yellow to black to white found in field collections is the same as that produced by heating alone; (2) color alteration is progressive, cumulative, and irreversible; (3) color alteration is time and temperature dependent and virtually independent of pressure; and (4) color alteration in conodonts correlates well with fixed carbon, vitrinite reflectance, mineral diagenesis, and isopach data. The color alteration index of conodonts is a valuable method for assessing thermal metamorphism because (1) it is rapid and inexpensive and requires only standard laboratory techniques and a binocular microscope; (2) conodonts extend virtually intact into garnet-grade metamorphism, well beyond the range of other organic indexes; (3) conodonts are most abundant and most easily concentrated from marine carbonate rocks, whereas phytoclasts are least abundant in and often absent from these same rocks; and (4) vitrinite, one of the main types of phytoclast, is limited to post-

Silurian rocks, whereas conodonts extend into the Cambrian.

Thermal effect on Triassic rocks by contact metamorphism

Triassic fluvial and lacustrine sedimentary rocks in the Culpeper basin, Va. (loc. 1, index map), consist chiefly of conglomerate, siltstone, shale, and calcisiltite. According to K. Y. Lee, these rocks were extensively metamorphosed in contact with diabase. After deposition, they were monoclinally tilted westerly and northwesterly; block-faulted, locally folded, and synkinematically intruded diabase fissure flows emanated from near-surface diabase intrusions; and contact aureoles formed adjacent to the diabase. The progressive advance of thermal effects in the aureoles is characterized by different mineral assemblages. Biotite--cordierite-quartz spotted hornfels and hypersthene-quartz quartzites represent arenaceous and argillaceous sediments near diabase succeeded outwardly by cordierite-quartz-andalusite spotted hornfels and the appearance of chlorite, epidote, and quartz. Lime garnet-diopside-tremolite-idocrase skarns form in calcareous sediments. Subsequently, hydrothermal alteration and copper and iron mineralization occurred in the aureoles, diabase bodies, and fissure flows during the late stage of diabasic magma differentiation. The width of the aureoles is generally less than 1.6 km, but a wider aureole was formed in areas of soft sandstone and conglomerate in contact with a large alkaline diabase mass.

Probable Miocene age for the Pensauken gravel in the Delmarva Peninsula

J. P. Owens reported that dating the widespread gravel sheets of the emerged northern Atlantic Coastal Plain (loc. 2) has long been conjectural because of the almost total absence of fossil remains. In the lower Delmarva Peninsula, however, one of these gravel sheets (the Pensauken Formation) appears to interfinger with a thick sequence of interbedded dark-colored clay, sands, and gravels. Locally, these beds contain fossils that are latest Miocene in age. On the basis of this relationship and the regional relationship of this gravel sheet to others in the same general area, it now seems that most of the widespread gravels of the northern Atlantic Coastal Plain are Miocene or perhaps earliest Pliocene in age.

Conodont geothermometry indicates slaty cleavage formed at elevated temperatures

Reconnaissance field investigations in the Appalachian basin by J. B. Epstein and A. G. Epstein using conodonts as geothermometers showed that a temperature of about 200°C coincides with the initiation of slaty cleavage. The color of conodonts changes from amber to black with increasing time and temperature, as shown by experimental heating and corroborated by the field studies. Overburden is the cause of increased temperatures. The Martinsburg Formation of eastern Pennsylvania (loc. 3), with its well-developed cleavage, appears to have reached about 300°C. These observations support the argument that slaty cleavage develops under metamorphic conditions.

Slumping reactivated in bluffs of Sandy Hook Bay, New Jersey

Slumping of considerable displacement renewed in the pile of chiefly unconsolidated marine sediments in the Atlantic Highlands of New Jersey (loc. 4) in late summer 1972, according to J. P. Minard. Older slump blocks were mapped and described by Minard (1969). During restudy, several interesting aspects of the role of natural processes and the influence of man on these features were revealed. It was learned that one large block had slumped as recently as 1972. This block had a surface area of possibly 16 ha and may have included as much as several million cubic metres of soil and rock. The pre-1972 slumping probably was caused

by a combination of factors such as a high water table and undercutting of bluffs by waves and tidal currents. The slumping renewed in 1972 involved a land surface about 0.8 km long, up to 76 m wide, and possibly from 15 m to 61 m deep, a total volume of perhaps 600,000 to 800,000 m^3 of soil and rock. The slump blocks may not have been recognized by municipal planners or construction engineers; construction of sewer lines and large buildings was planned and undertaken at locations of definite potential geologic hazards. Results of the study are published (Minard, 1974). This slumping also probably involved a combination of natural factors but may have been more influenced by man's activities than was the earlier slumping.

Tectonics and geochronology in the Piedmont of northeastern Virginia

The Fredericksburg complex (loc. 5), as defined by Louis Pavlides and others (1974, p. 569), is a tectonic unit that consists chiefly of schist and gneiss that have been extensively intruded by felsic plutons and dikes and sills. It is overlain on its eastern side by Coastal Plain sediments; its western boundary coincides with the first appearance (eastward) of felsic dikes and sills. Recent mapping by Pavlides near the Rappahannock River and west of Fredericksburg, Va., has shown that the Fredericksburg complex contains at least two mappable formations. In its westernmost part the Fredericksburg complex includes part of the Quantico Slate, which here is a high-grade crystalline schist. The other formation is a biotitic hornblende gneiss that occurs in the eastern part of the complex and conformably overlies the Quantico. Although a few generally poorly developed sedimentary features suggest that the biotitic hornblende gneiss stratigraphically as well as structurally overlies the Quantico, it is possible that the gneiss has been thrust above the Quantico. Both the Quantico and the biotitic gneiss have a pronounced foliation (S_1) parallel to and generally conformable with bedding (S_0) as defined by schistose and gneissic quartzitic layers within each formation. Both S_0 and S_1 have been folded along northeast-trending axes to produce a series of open, upright, northeast-plunging folds with local axial plane foliation (S_2). A gently plunging (10° to 35°) lineation, which is ubiquitous in the Fredericksburg complex, is parallel to the axes of some of these folds.

The number of granitic dikes and sills increases from west to east across the Fredericksburg complex, as does the grade of metamorphism, from staurolite in the west to sillimanite in the east. A microcline granite gneiss with two foliations occurs in the northeastern part of the Salem Church quadrangle and the southeastern part of the Storck quadrangle and is herein named the Berea pluton. This pluton appears to be a generally concordant intrusion within the biotitic hornblende gneiss, which it also locally crosscuts near its contact. A weak foliation (S_1) defines its general structural concordance with the folds of the enclosing gneiss. Well-developed, steeply dipping, northeast-trending biotite folia define the regional foliation (S_2) of this pluton, which is concordant with the S_2 of the enclosing gneiss. Zircons separated from one locality in the microcline granite gneiss of the Berea pluton and analyzed by T. W. Stern give the following nearly concordant ages by use of the most recently ascertained half lives: $^{206}Pb/^{238}U$ yields an age of 346.8 m.y., $^{207}Pb/^{235}U$ yields 348.6 m.y., and $^{207}Pb/^{206}Pb$ yields 360.6 m.y. These ages indicate that the youngest regional foliation (S_2) within the Berea pluton and its enclosing country rocks is younger than 360 m.y. and is a structure of Acadian age or younger.

Palynology

According to L. A. Sirkin, studies of the pollen and spores from a few localities in the barriers cropping out at elevations near 24 m above sea level near Charleston, S.C. (loc. 6), showed these microflora to have characteristic Tertiary (as evidenced by the presence of Pterocarya) aspects rather than Pleistocene aspects. Apparently, the Pleistocene sea did not exceed this level in this area, although any number of authors have indicated that it did.

Abundance of Catoctin mafic dikes in Virginia indicates scale of late Precambrian crustal distention

G. H. Espenshade reported that metadiabse feeder dikes to the upper Precambrian Catoctin Metabasalt lavas are widespread in the older Precambrian plutonic rocks and overlying metasedimentary rocks (Lynchburg and Swift Run Formations) in the northern part of the Blue Ridge anticlinorium (loc. 7). Continuous exposures in pipeline trenches in the Rectortown quadrangle showed these dikes to be far more abundant than surface exposures suggest. The total thickness of dikes in a section of pipeline trench 4.5 km long amounted to about 20 percent of the total rocks; in another section of trench 1 km long, the dikes made up 15 percent of the total. About 90 percent of the dikes are less than 15 m thick; very few dikes are more than 30 m thick.

The great volume of Catoctin Metabasalt lavas and metadiabase dikes in the Blue Ridge anticlinorium was probably erupted during a period of continental rifting in the late Precambrian (Rankin, 1972). In northwestern Newfoundland, very similar basalt flows fed by dikes cutting the older Precambrian basement are also judged to have been erupted during a rifting stage, either in the late Precambrian or early Paleozoic (Strong and Williams, 1972). Some measure of the scale of crustal distention accompanying this continental rifting and basalt eruption is given by the total volume of feeder dikes. In the Rectortown quadrangle, crustal distention appears to have been on the order of 15 to 20 percent.

Gravity data indicate mafic body near District of Columbia

Gravity measurements in the District of Columbia and Maryland (loc. 8) revealed a northeasterly elongated gravity high with sharp gradients according to D. L. Daniels. The anomaly, which is 5×17 km, extends from the center of Washington, D.C., to College Park, Md., and may be caused by a mafic body in the Piedmont rocks, here covered by a thin veneer of Coastal Plains deposits. The body is probably related to the so-called Baltimore Gabbro Complex, as used by Herz (1951), which is on trend to the north.

Prominent spheroidal features exposed by strip mining

Large spheroidal features in the highwall strata of strip mines were noted by V. A. Trent during the geologic mapping of the Anawalt quadrangle (loc. 9) in McDowell County, W. Va. These features are up to several metres in diameter, have a flattened ellipsoidal to round shape, and occur in competent and incompetent strata consisting of sandstone, siltstone, and shale of the Pocahontas and New River Formations of Pennsylvanian age. These features are most conspicuous near the tract of the axial plane of the Dry Fork anticline, a major structural feature in the area, and appear to be related to jointing.

CENTRAL REGION AND GREAT PLAINS

KENTUCKY

Geologic mapping

A cooperative project with the State, begun in 1960, was more than 86 percent completed by May 1, 1975, when 512 geologic maps had been printed (fig. 1), another 52 maps had been approved for publication, and an additional 45 were undergoing editorial review. Geologic mapping was in progress in 75 quadrangles. About 710 maps will be published to cover 763 7½-min quadrangles that are wholly or partly within the State. The geologic maps are printed on recent editions of topographic base maps of quadrangles, at 1:24,000 scale, and published in the geologic quadrangle map series.

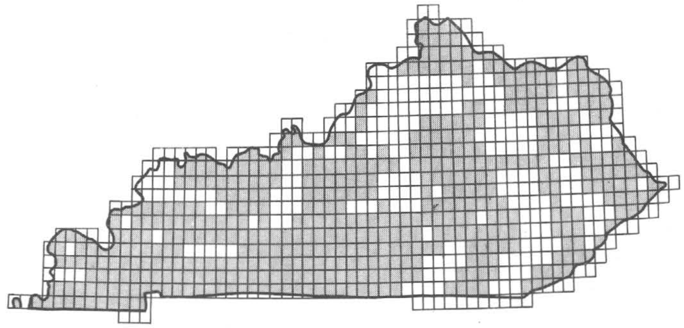


FIGURE 1.—Published geologic quadrangle maps (patterned area) of Kentucky as of May 1, 1975; small squares are 7½-min quadrangles.

Lithostratigraphy and depositional environments of the Lexington Limestone

E. R. Cressman (1973) found that the Ordovician Lexington Limestone of central Kentucky (loc. 1, index map) consists of 11 complexly intertongued members that are composed of fossiliferous and bioclastic limestone and shale that were deposited in a marine intralittoral zone of the Appalachian geosyncline. Transgression and regression of rock types resulted from varying rates of subsidence that were unrelated to the Cincinnati arch or the Jessamine dome. Subsidence of the southern part of the area during the later part of Lexington time may have been the result of displacement along the Kentucky River and the Irvine-Paint Creek fault zones. Calcarenites of the Lexington contain an average of 2.4 percent P_2O_5 present as cryptocrystalline carbonate-fluorapatite that occurs as fillings and replacements of small fossils.

New data on eastern Kentucky coal resources

Mapping of low- to medium-sulfur coal beds in southern Lawrence and northern Johnson Counties, Ky. (loc. 2), by P. T. Hayes, C. L. Pillmore, D. E. Ward, D. C. Alvord, and C. W. Connor added to the national coal resources in the proven and indicated categories. Many well-known coal beds that are commercially developed to the southeast thin toward and within the mapped area. Although a few of these beds are locally thick enough to be stripped,

STATES IN CENTRAL REGION
AND GREAT PLAINS

they have little potential for large-scale underground mining.

Geologic and hydrologic information for land-use planning in the Kentucky River Area Development District

Experimental maps were prepared by W. L. Newell and R. E. Davis largely from preexisting data for the headwaters area of the Kentucky River (loc. 3), eastern Kentucky, an eight-county region designated the Kentucky River Area Development District (KRADD) by the Appalachian Regional Commission. These maps have been presented to KRADD planners in a format and terminology usable by local people untrained in Earth science. Time and cost limitations required a regional analysis with detailed, large-scale examples of selected localities.

Most of the maps produced to meet these needs show the abundance and distribution of naturally occurring materials and the domain and intensity of geomorphic processes. Three types of maps showing current land use, slope, and flood-prone areas present both basic and derived data directly applicable to specific land-use decisions. Basic map information on quality and quantity of surface and ground water, bedrock and surficial geology, and mineral fuels can be interpreted for a wide variety of current and potential uses.

Accompanying texts explain bedrock control of geomorphic processes, distribution of surficial deposits, and hydrologic characteristics of the intensely dissected eastern Kentucky terrane. Within this conceptual framework, geomorphic processes and the landscape can be evaluated in humanly significant terms of low to high potential risk and thus indicate the opportunities and limitations for land use.

MICHIGAN AND WISCONSIN

Preglacial topography

Research by geochemical methods in the Michigan part of the Sault Ste. Marie 2° quadrangle (loc. 4) to find areas that may have potential for economic metallic and nonmetallic deposits was begun by J. W. Whitlow and J. F. Windolph. A study of available data indicates an overburden comprising lacustrine and glacial deposits up to 130 m thick. The overburden locally is thickest near Lake Superior and thins southward to a thickness of 64 m near the north shore of Lake Michigan. Bedrock crops out at many places and ranges from dolomite and limestone south of lat. 46°20′ N. to sandstone and minor quartzite north of lat. 46°20′ N. Bedrock outcrops and available water-well data were used to outline roughly the valleys and hill areas of the preglacial topography, which had greater relief than the present topography.

Paleomagnetic studies in Houghton County, Michigan

According to K. G. Books, results of preliminary paleomagnetic determinations for rock samples from Keweenawan lava flows at Silver Mountain and Sturgeon Falls in Houghton County, Mich. (loc. 5), showed a reversed polarity and a direction of remanent magnetization similar to those in the South Range lava flows near Ironwood as well as to those in other Keweenawan rocks around Lake Superior. This polarity and this direction of magnetization are unique to lower Keweenawan rocks in the Lake Superior area.

Archean volcanic pile, Wakefield area, Michigan

Metamorphosed volcanic rocks of Archean age (Precambrian W) in the Wakefield area (loc. 6) form a south-dipping monocline composed of older andesitic flows and mafic to intermediate pyroclastic rocks to the north and younger felsic schists and pyroclastic rocks to the south. W. G. Prinz postulated that these volcanic rocks represent the remnants of the central and upper parts of what was once probably a much larger differentiated volcanic pile. The andesitic flows in the Wakefield area are similar to flows found in the central parts of more completely exposed Archean volcanic piles in Canada.

The flows pass upward (southward) and westward into felsic rocks typical of the upper parts of Archean volcanic piles. Thickening of the felsic schists to the west suggests that the Wakefield area lies on the eastern side of a center of felsic eruption. The western side of this center is cut off by intrusive quartz monzonite. Basaltic flows typical of the base of Archean volcanic piles are not exposed in the Wakefield area; they may lie at depth to the north or may have been removed by erosion prior to deposition of overlying Precambrian X rocks.

Proposed repetition of strata by faulting, eastern Gogebic County, Michigan, and north-central Wisconsin

Six northeast-trending units have been mapped between Marenisco and Watersmeet in eastern Gogebic County, Mich. (Fritts, 1969). The predominant lithologies in these units are (from northwest to southeast) metavolcanic, graywacke, metavolcanic, graywacke, metavolcanic, and graywacke. Iron-formation occurs in each volcanic unit and in the southernmost graywacke unit. The units dip steeply to the southeast, and the top directions, as determined by graded bedding in the middle graywacke and pillow structures in mafic flows in the southernmost metavolcanic unit, all face southeast. Fritts interpreted this as a thick conformable sequence forming a simple monocline.

C. E. Dutton traced the extensions of these units as far as 72 km to the southwest into Wisconsin (loc. 7). He noted that the two oldest units, according to Fritts' interpretation, are free of granitic intrusive rocks and are of low metamorphic grade, whereas the postulated younger units are cut by intrusive rocks and are of high metamorphic grade. Dutton concluded that these six units do not represent a continuous section. He suggested that the three metavolcanic units are correlative, as are the three graywacke units, and that they are repeated along northeast-trending strike faults. The individual volcanic units are older and are overlain conformably by the graywacke unit to the southeast, whereas the middle and southern metavolcanic units are faulted against the graywacke unit to the northwest. The twofold metavolcanic-graywacke sequence is thus repeated three times across the area.

In Wisconsin, the southernmost unit has been folded along northeast-trending axes and intruded along its southern limit by granite, accompanied by the development of kyanite and, locally, staurolite in schists formed from the graywacke.

MINNESOTA

Volcanic sedimentary sequences in the Vermilion district, Minnesota

Two sequences of Precambrian W volcanic-sedimentary rocks were distinguished by P. K. Sims in the Vermilion district, northeastern Minnesota (loc. 8). The two sequences, which are separated by a major dip-slip fault that has an estimated vertical displacement of at least 1,000 m, differ in metamorphic grade and possibly are of different ages.

The sequence on the southern side of the fault is weakly metamorphosed and has long been considered the classical sequence of lower Precambrian rocks in northern Minnesota. It consists of a lower mafic volcanic succession (Ely Greenstone, about 6,500 m thick) that is succeeded upward stratigraphically by felsic volcanic rocks and volcanogenic graywacke-argillite (Lake Vermilion Formation, about 3,000 m thick, and Knife Lake Group, about 4,500 m thick). A second younger mafic volcanic succession (Newton Lake Formation, about 1,500 m thick) overlies the Knife Lake Group. It contains numerous differentiated mafic-ultramafic sills or flows as much as 200 m thick that have been interpreted by K. J. Schultz (Univ. of Minnesota) as having been formed from a magnesian basalt magma by crystal settling. The ultramafic rocks at the base of the sills contain about 5,000 ppm Cr; nickel concentrations associated with the sills have not been found.

The sequence on the northern side of the fault consists of amphibolite-facies volcanic and sedimentary rocks and is associated with granitic rocks in the Vermilion Granite-migmatite massif (Southwick, 1972). Geologic mapping by Sims in the Shagawa Lake 7½-min quadrangle near Ely has shown that this northern sequence consists mainly of metamorphosed basaltic lava flows, some of which have discernible pillow structures, metagabbro, felsic tuff, and graywacke-argillite. The oldest unit in the Shagawa Lake quadrangle is a dacitic tuff or flow, which apparently was partially mobilized during the Vermilion Granite magmatic episode. Because of its physical appearance, trondhjemitic composition, and intrusive relation to adjacent rocks, this rock unit was earlier named the Burntside Granite Gneiss by F. F. Grout (1926).

NEBRASKA AND KANSAS

Bedrock geologic map and thickness of Quaternary deposits

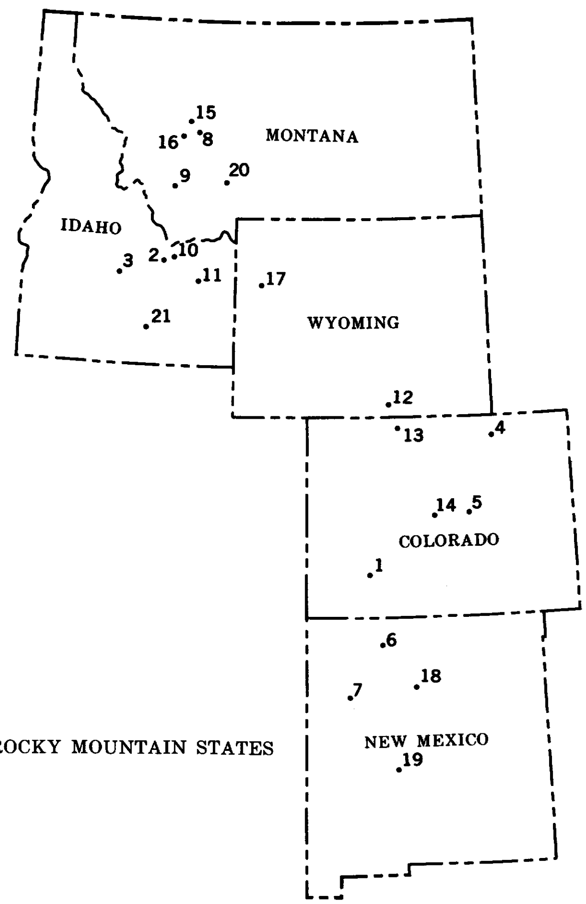
Data from test-hole logs, published and unpublished maps, and field notes from the files of the

Nebraska Geological Survey were used by G. E. Prichard (USGS) and R. R. Burchett, E. C. Reed, and V. H. Dreeszen (Nebraska Geological Survey) in compiling a bedrock geologic map of part of eastern Nebraska and northernmost Kansas (loc. 9). Bedrock outcrops are shown. The map, which also shows the combined thickness of Quaternary surficial deposits of loess, till, alluvium, and lake sediments, is at a scale of 1:250,000. The map should be useful for land-use planning and other activities such as mining and water-well drilling.

ROCKY MOUNTAINS

Multiple ages of middle Tertiary mineralization in the western San Juan Mountains

Potassium-argon and fission-track ages on vein feldspars and micas, as well as on mineralization-related intrusions, indicated that middle Tertiary mineralization in the western San Juan Mountains in Hinsdale County (loc. 1, index map) occurred intermittently from about 30 to 10 m.y. ago, according to P. W. Lipman, F. S. Fisher, H. H. Mehnert, and C. W. Naeser. This span is essentially the same as that of the associated igneous activity.



ROCKY MOUNTAIN STATES

Mineralization recurred during the waning stages of evolution of individual volcanic centers, including several precaldera central volcanoes and also the large Uncompahgre, San Juan, Silverton, and Lake City calderas. Much of the richest mineralization, localized within the Silverton caldera area, was emplaced 5 to 15 m.y. later than the time of caldera formation about 27.5 m.y. ago, however, and appears genetically unrelated to evolution of this caldera and its associated magmatic system. This economically significant mineralization seems most closely related to volumetrically minor intrusions of quartz-bearing silicic porphyry, an association that is also common elsewhere in the Rocky Mountain region.

STRATIGRAPHIC STUDIES

Ordovician sedimentation in the Western United States

R. J. Ross, Jr., found that Ordovician sedimentation in the Western United States was influenced mainly by the changing position of the transcontinental arch relative to the Earth's latitudinal belts and to sea level. Paleomagnetic studies have shown that in Early Ordovician time the North American Continent was near the equator and that the arch was oriented east-west at about lat. 10° S. (McElhinney and Opdyke, 1973). Carbonates of Tremadocian and Arenigian Age south of the arch were mostly dolomite, formed under shallow restricted water in the horse latitudes (about 20° from the equator). A gastropod-nautiloid fauna of low diversity inhabited this environment. North of the arch, abundantly fossiliferous limestone formed in well-circulated equatorial waters.

Late Arenigian (late Canadian) lowering of sea level exposed older sedimentary rocks and crystalline rocks along the site of the arch and on the Canadian Shield to extreme tropical weathering. Quartz sand was released and swept westward south of the transcontinental arch by the southern trade winds to form the Everton Formation and parts of the Simpson Group; as sea level rose, the transgressive St. Peter Sandstone and sands of the upper part of the Simpson Group were deposited.

North of the arch, the sand (Winnipeg Formation, Swan Peak Quartzite, and Eureka Quartzite) was swept westward by northern trade winds to overwhelm the carbonate deposits on the platform and shelf beneath a prograding blanket. By middle Caradocian to Ashgillian (Cincinnatian) time, the source area of the sand on the Canadian Shale was inundated.

As transgression reached its maximum, evaporation of this enormous expanse of shallow sea caused centripetal flow of normal marine surface water and centrifugal flow of hypersaline bottom water. The latter converted lime muds to dolomite. A gastropod (*Maclurites*) nautiloid fauna characterized the resulting facies. Sessile bottom-dwelling organisms could survive only where surface water washed carbonate banks.

Dilution of the underflowing brines with normal seawater caused the precipitation of dissolved silica as chert to form the peripheral facies, which contains graptolites and radiolarians.

Mississippian history of the northern Cordilleran region

In a synthesis of stratigraphy of the Mississippian of the northern Cordilleran region, W. J. Sando recognized two principal depositional cycles separated by a cycle of epeirogenic uplift and erosion. Each depositional cycle is divisible into phases that represent significant changes in depositional patterns. During cycle I (early Kinderhookian to early Meramecian), predominantly carbonate and evaporite deposition occurred on a broad cratonic shelf bordered on the east by land and on the west by a deep trough that received terrigenous sediments from an adjacent western land mass. Kinderhookian transgression was followed by regression during the Osagean and early Meramecian. Regional uplift during latest early Meramecian time (cycle II) drained the shelf area and caused the sea to be confined to the western trough. During cycle III (middle Meramecian to Chesterian) the sea again transgressed onto the craton, which was differentiated into the Big Snowy-Williston, Wyoming, and Uinta basins and which received terrigenous and carbonate sediments. The Big Snowy-Williston basin was uplifted during latest Chesterian time and lost its identity, but the Wyoming basin continued to expand into the Pennsylvanian, when it engulfed most of the Cordilleran platform and breached the transcontinental arch.

Stratigraphy of southern Beaverhead Mountains, Idaho

G. F. Embree, R. D. Hoggan, E. J. Williams (all of Ricks College) and Betty Skipp (USGS) (1975) reported that a 3,000-m-thick incomplete sequence of mainly miogeosynclinal Paleozoic rocks occurs in the southern Beaverhead Range, Clark and Lemhi Counties (loc. 2), where it is unconformably underlain by the Wilbert Formation (Precambrian Z) and capped by a remnant of Triassic rocks. The Wilbert Formation is more than 600 m thick and is overlain by as much as 30 m of Kinnikinc Quartzite (Ordovician). Above the Kinnikinic, the Jefferson Formation (Devonian) ranges from 0 to 65 m thick. Thin, unnamed Upper Devonian and Lower Mississippian shale, siltstone, and limestone unconformably overlie all older rocks and are gradationally overlain by about 1,000 m of limestone of the Middle Canyon Formation (Mississippian). About 300- to 400-m-thick, intensely deformed massive limestones of the Scott Peak Formation (Mississippian) overlie the Middle Canyon. Less deformed Mississippian limestones of the South Creek and Surrett Canyon Formations locally overlie the Scott Peak and are about 200 m thick. The uppermost Mississippian formation, the Big Snowy, which is about 200 m thick, is conformably overlain by Pennsylvanian sandstone, which grades upward into Pennsylvanian and Lower Permian alternating sandstone, limestone, and dolomite totaling about 975 m in thickness. The uppermost 95 m of the Paleozoic sequence is interbedded chert and phosphatic limestone and shale of the Phosphoria Formation (Permian).

Local eastern source for Pennsylvanian turbidites in Wood River Formation, Idaho

Middle and Upper Pennsylvanian turbidite conglomerate and sandstone with an eastern source—probably an emergent Copper Basin Formation (Mississippian) flysch terrane—are present in the easternmost known exposures of the Wood River Formation in Blaine County, Idaho (loc. 3) (Skipp and Hall, 1975). A folded and faulted thrust, the trace of which trends about N. 20° W. for 9.6 km across the Fish Creek Reservoir area, brings the Wood River Formation over the Copper Basin Formation. The Wood River Formation is more than 520 m thick in the Fish Creek area. Turbidite conglomerate is abundant only in easternmost exposures and is interbedded with the typical fine-grained limy sandstone and sandy limestone of the Wood River in its type area. General lithologies, faunas identified by R. C. Douglass, and petrographic studies by J. N. Batchelder showed that the conglomerate derived from the east occurs in stratigraphic sequences that correlate with units 2, 3, 4, 5, and 6 (lower part) of the Wood River Formation in the type area. Conglomerates of unit 1, the Hailey Conglomerate Member of the Wood River Formation, probably have a different source than the local turbidites of the higher stratigraphic units discussed here.

Stratigraphy of the Pierre Shale (Upper Cretaceous) in the northwestern Denver basin

Recent investigations of the Pierre Shale (Upper Cretaceous) in southeasern Wyoming and northern

Colorado (loc. 4) by L. W. Kiteley (1975) provided evidence that sandstone units previously assigned to the Terry Sandstone Member are both older and younger than the type Terry near Fort Collins, Colo. The type Terry, so far, has not been traced on the surface beyond its type locality. The sandstone that is called Terry in the subsurface of the Denver basin may be only partly equivalent to the type Terry. Mapping of outcropping sandstone units at Francis Ranch in southeastern Wyoming, which are younger than *Baculites jenseni* and older than the Fox Hills Sandstone, has demonstrated that these units range in thickness from about 30 to 120 m and were deposited in shoreface and foreshore environments as very fine to medium-grained sands. The correlation of outcrops and well logs indicates that these sandstones are widespread in the northern Denver basin.

Comparison of the outcropping Pierre Shale at Francis Ranch with laterally equivalent rocks in the Denver, Hanna, Laramie, and Powder River basins indicates that use of the names Sussex and Shannon Sandstone Members of the Steele Shale, and Parkman Sandstone Member of the Mesaverde Formation, when applied to rocks in the Denver basin, should be abandoned. The Sussex and Shannon, at the type sections in the Powder River Basin, are equivalent in age to the upper part of the Niobrara Formation and overlying Gammon Ferruginous Member (equivalent) of the Pierre Shale in the Denver basin. The Hygiene Sandstone Member of the Pierre Shale in the Denver basin is about the same age as the Rock River Formation in the Laramie Basin and the Parkman Sandstone Member of the Mesaverde Formation in the Powder River Basin. In the Denver basin, the name Hygiene Sandstone Member should be substituted for Shannon, the name Terry Sandstone Member should be substituted for Sussex, and the names Rocky Ridge, Larimer, and Richard Sandstone Members should be substituted for Parkman.

Castle Rock Conglomerate extended

Separate studies by P. E. Soister and L. W. McGrew in the Denver basin (loc. 5) extended the area known to be underlain by the Castle Rock Conglomerate of Oligocene age. Originally, much of the Tertiary rock of the region was assigned to the so-called Monument Creek beds and considered to be Miocene (Hayden, 1874) or Oligocene (Darton, 1905). After Lee (1902) and Richardson (1912) separated the Monument Creek beds into two formations—the Dawson Arkose of Eocene (later called Late Cretaceous and Paleocene) age and the Castle Rock Conglomerate of Oligocene age—the area believed to be underlain by Oligocene rocks was considerably restricted (Richardson, 1915). Vertebrate fossils collected during the recent work and identified by G. E. Lewis (USGS) and P. O. McGrew (Univ. of Wyoming) showed that the Castle Rock Conglomerate extends northeast from the area mapped by Richardson (1915) to 40 km east of Denver. Reconnaissance by both Soister and McGrew suggested that erosional remnants of the Castle Rock Conglomerate extend 10 to 20 km southeast of those mapped by Richardson (1915).

Ammonite zonation of upper part of Lewis Shale, San Juan basin

A study by W. A. Cobban, E. R. Landis, and C. H. Dane (1974) of the ammonite faunal zones of the upper part of the Lewis Shale of Cretaceous age along the eastern side of the San Juan basin in Rio Arriba County (loc. 6) confirmed the previously published conclusions of J. E. Fassett and J. S. Hinds (1971) that there is a southwestward increase in the age of the top of the Lewis Shale across the basin. The uppermost part of the Lewis Shale in the Dulce area probably lies in the zone of *Baculites compressus*, whereas in the Regina area about 80 km south of Dulce the uppermost part of the Lewis lies several ammonite faunal zones lower.

Cretaceous stratigraphy, southern San Juan basin

The Borrego Pass Lentile (Upper Cretaceous) of the Crevasse Canyon Formation (Correa, 1970) can be differentiated from the overlying Mulatto Tongue of the Mancos Shale in the southern part of the San Juan basin in New Mexico (loc. 7), according to J. F. Robertson. The differentiation is based on lithologic character, depositional environments, and the separation of these formations by an unconformity. The Borrego Pass, informally called the stray sandstone, consists of very light gray, very fine to medium-grained, well-sorted sandstone and interbedded carbonaceous siltstone and shale that were apparently deposited in a strand plain environment. Thin lenticular beds at the base of the Mulatto Tongue, on the other hand, generally consist of poorly sorted, calcareous, fine-grained to conglomeratic sandstone that contains fossil clam shells and shark's teeth and that grades in many places into a hash of broken shells.

IGNEOUS STUDIES

Lower crustal and upper mantle nodules in the Ming Bar diatreme, Big Belt Mountains

The Ming Bar diatreme penetrates a complexly folded and thrusted sequence of sedimentary rocks in the northern Big Belt Mountains of Montana and was discovered by G. D. Robinson and M. E. McCallum during mapping of the Beartooth Mountain quadrangle (loc. 8). The pipe contains nodules of granulite, pyroxenite, and peridotite of probable lower crustal and upper mantle origin. The matrix is alkali olivine basalt of unusually magnesian composition and contains abundant megacrysts of olivine and chrome diopside. The upper portion of the pipe is choked with large foundered blocks of Cretaceous sedimentary units, and material along the pipe margins is intensely brecciated and granulated.

Microprobe analysis of representative nodule and matrix suites by D. H. Eggler (Geophysical Laboratory) permitted the determination of *P-T* equilibration values for mineral phases and thereby provided a basis for estimating depths of crystallization. Pyroxene and spinel chemistry indicates that granulites and pyroxenites are related to each other and most likely originated in the lower crust. The more magnesian peridotite assemblage includes spinel lherzolite, harzburgite, and wehrlite and was probably derived from an upper mantle source. Olivine and chrome diopside megacrysts may also be accidental inclusions of mantle or may be cognate to the magnesian basalt of the diatreme, which contains phenocrysts that are chemically indistinguishable from the megacrysts. The wehrlite could also be cognate to the basalt.

Eocene volcanic rocks in the Pioneer Mountains, Montana

Volcanic rocks, dominantly basaltic to latitic flows, occur in the Pioneer Mountains, Mont. (loc. 9), and nearby areas, where they are being studied by E-an Zen. The presence of oxidized rubble and columnar jointing shows the emplacement to be entirely subaerial. Individual flows range from a few metres to as much as 50 m thick, and the intercalation of flows of different compositions and silica contents indicates the simultaneous presence of magma chambers from which these lavas were tapped. There are also several ash beds consisting mainly of rhyolitic pumice that include both water-laid reworked material and air falls. Some pumice fragments contain megascopic euhedral plutonic biotite, suggesting the presence of a granitic magma body whose top barely breached the land surface. Most, if not all, latitic and basaltic eruptions were through fissures (now dikes) rather than discrete centers; how the magmas of different compositions maintained their discrete plumbing systems is a mystery. Five K-Ar whole-rock dates by R. F. Marvin and H. H. Mehnert are from 46 to 49 m.y. (lower and middle Eocene). These volcanic rocks are thus contemporaneous with the Lowland Creek Volcanics near Butte or the Absaroka Volcanic Group east of the Yellowstone Park; petrographically, they are vastly different, and the flows may define a new volcanic field. The volcanic rocks are emplaced after the last folding and thrusting episodes in the area but are about synchronous with the development of regional shear cleavage, which affected some of the rocks, but elsewhere the cleavage surfaces provided conduits for the lava.

Bimodal rhyolite-basalt sequence on the northern margin of the eastern Snake River Plain, Idaho

Raymond Jeanloz (Amherst College) and D. L. Schleicher (USGS) (1975) mapped an unusually well exposed sequence of interlayered Pliocene to Holocene rhyolite and basalt about 400 m thick at Rattlesnake Point, 80 km northwest of Idaho Falls, Idaho (loc. 10). A rhyolitic welded tuff <10 m thick is intercalated with basalt flows that rest on Pennsylvanian limestones. Sources for the basalts include three pyroclastic cones; a fine-grained gabbro plug cuts one of the cones. A rhyolite flow about 3 km across and 250 m thick caps the basalt flows and cones. South of and topographically below the basalts are three other rhyolite flow masses whose map pattern suggests >130 m of displacement on a steeply dipping east-striking fault.

The basalt flows intertongue northward with coarse fan gravels, which overlie more steeply dipping welded-tuff sheets, including the Edie School Rhyolites of Scholten and others (1955). The intertonguing suggests contemporaneous volcanism and sinking of the plain relative to the surrounding highlands.

The eastern Snake River Plain, a composite volcano-tectonic depression

The eastern Snake River Plain (loc. 11) is a northeast-trending volcano-tectonic depression of Pliocene to Holocene age that cuts across earlier north-south- and northwest-trending Laramide and Basin and Range structures. Reconnaissance geologic mapping and synthesis of available data by H. J. Prostka and P. L. Williams indicated that the plain is a composite feature whose formation began with caldera collapse associated with major eruptions of rhyolitic ash-flow tuffs. These events were followed by re-

peated graben faulting and gentle warping interspersed with renewed rhyolitic and basaltic volcanism as shown by progressively steeper plainsward dips of successively older volcanic units. Northeastward migration of major rhyolitic volcanism with time is indicated by progressively younger ages of basal ash-flows tuffs in this direction.

Subsidence of the plain was accompanied by continued subsidence of marginal basins along reactivated Basin and Range faults. However, relatively greater subsidence of the plain itself along deep graben faults is suggested by the concentration of hot springs along both borders of the plain and by the alined abrupt terminations of the Lost River, Lemhi, and Beaverhead Ranges at the north edge of the plain. The continued influence of Basin and Range faults beneath the plain is suggested by the alinement of many young basaltic vents and rift zones on trend with major Basin and Range faults outside the plain.

Basaltic volcanism and rift zones in the Snake River Plain

Basaltic volcanic eruptions in the eastern Snake River Plain (loc. 11) are alined along rift zones, which may be related, in part, to older structures outside the plain, according to P. J. I. LaPoint. All of the most recent eruptions (Craters of the Moon, Wapi lava field, Hell's Half Acre lava field) are associated with north- to northwest-trending rift zones that are roughly parallel to Basin and Range faults on the adjacent flanks of the plain. A broad rift zone extends approximately 70 km west-northwest from Island Park. Small flows, alined fissure vents, small craters, and discontinuous fissures mark the location of the rift zone. The rift zone is roughly parallel to and approximately 25 km south of the crest of the Centennial Range.

Future basaltic eruptions are more likely to occur on the most recently active rift zones in the Snake River Plain or on projections of active faults adjacent to the plain.

Emplacement and deformational history of the Keystone Quartz Diorite pluton, Wyoming

The Keystone Quartz Diorite of Houston and others (1968) borders the western and southwestern margins of the Lake Owen Mafic Complex of Stansrud (1962) in the southern portion of the Albany quadrangle in Albany and Carbon Counties, Wyo. (loc. 12). Although relationships of the quartz diorite pluton with rocks of the layered mafic sequence are uncertain, mapping by M. E. McCallum suggested that the quartz diorite is younger than the mafic complex. Gabbroic inclusions are abundant locally, and several larger, irregular to lenticular masses of gabbro are characterized by "intrusive breccia" contacts where quartz diorite has clearly invaded the gabbro. The gabbro and the quartz diorite both may have been derived from the same fractionating magma. Younger gabbroic and granitic magma invaded the quartz diorite along planes of primary foliation to form sills, some of which contain intrusive(?) breccia that consists of felsic material engulfing mafic fragments and blocks. The latter hybrid sills may represent products of "mixed magma" crystallization. The sills were subsequently folded; several granitic dikes cut across this "fold fabric;" locally, copper-bearing faults postdate the dikes.

Rawah batholith, a pluton of Boulder Creek age in northern Colorado

A large pre-Silver Plume pluton emplaced into a sillimanite-grade metasedimentary sequence was recently recognized by M. E. McCallum in the Medicine Bow Mountains of northern Colorado (loc. 13). Its precise limits have not been established yet; however, the pluton exceeds 965 km^2 in area and underlies the Rawah Range for which it has been named. Batholith rocks range from quartz diorite to granite, but the predominant rock type is a biotitic plagioclase-rich quartz monzonite that is locally hornblende bearing. Appreciable assimilation is reflected by variation in bulk composition adjacent to host-rock inclusions. Medium- and coarse-grained equigranular rocks are most abundant; fine-grained and porphyritic rocks also occur; the latter locally have a rapakivi texture. Foliation is commonly well developed and is mainly of cataclastic origin, although alinement of tabular feldspars and biotite along with schlieren and small inclusions in some rocks is probably primary. At least two unrelated major episodes of pre-Silver Plume cataclasis affected these rocks. The first episode of cataclasis (and in part protoclasis) apparently accompanied and followed syntectonic intrusion associated with the high-grade regional metamorphic events responsible for the sillimanite-facies metamorphism and produced foliations roughly conformable with those of deformed host rocks. The second cataclasis occurred well after batholith emplacement and is related to shear zones.

Compositional, textural, and structural relationships show similarities to those of plutons of the 1,700+ m.y. Boulder Creek Granite to the south. Preliminary Rb-Sr whole-rock ages determined by

C. E. Hedge are approximately 1,710 m.y. and confirm a Boulder Creek age for the Rawah batholith.

Eocene porphyries in the Colorado mineral belt

Potassium-argon ages of biotite from monzonite, quartz monzonite, and porphyritic quartz monzonite collected by Bruce Bryant in Summit and Park Counties east and southeast of Breckenridge, Colo. (loc. 14), determined by Bruce Bryant, R. F. Marvin, H. H. Mehnert, and C. W. Naeser (1975) are 49.4±1.7, 43.0±1.5, and 43.8±1.5 m.y., respectively. These ages show that intrusion and mineralization in that part of the Colorado mineral belt were of late Eocene age. The intrusive rocks are younger than the latest movements on the Williams Range-Elkhorn fault system at the western margin of the Front Range.

Fission-track ages of zircon, sphene, and apatite from these rocks determined by Naeser are concordant within the limits of analytic uncertainty, but they are 5 to 10 m.y. younger than the K-Ar ages.

Biotite from a bed of crystal tuff about 1,500 m above the base of the Tertiary basin fill in South Park is 58.4±2.0 m.y. old, an age comparable with the K-Ar whole-rock age of 56.8±2.6 m.y. of an andesite from near the base of the fill reported by Sawatzky (1969). These deposits are folded and overridden along the Elkhorn reverse fault by Precambrian rocks of the Front Range uplift.

STRUCTURAL AND GEOPHYSICAL STUDIES

Five distinct types of thrust faults in the eastern Holter Lake region, northern Big Belt Mountains

Several types of thrust faults are well expressed in the eastern Holter Lake portion of the Montana disturbed belt (loc. 15). At least five distinct thrust types were recognized from mapping by G. D. Robinson, W. D. Myers, W. H. Hays, and M. E. McCallum, and these thrusts apparently reflect two dissimilar, major, time-related styles of deformation. The first and earliest deformational style is expressed by shallow-dipping thrust sheets of large displacement, some of which were folded during transport (type 1) and some of which were apparently folded mainly or entirely after transport (type 2). Type 1 thrusts are highly deformed (overturned and recumbent traces are common), and plates are generally overridden by the progressively younger, less deformed type 2 thrusts [e.g., the Eldorado thrust in Upper Holter Lake quadrangle (Robinson and others, 1969)]. The second and younger deformational style is expressed by higher angle thrusts that are concentrated primarily in a belt along the northeastern margin of the zone of thrusting. Some of these faults cut plates of the older deformed sheets. Included in the group of higher angle thrusts are three types: (1) high-angle folded thrusts, (2) imbricate, attenuated limb thrusts associated with overturned folds, and (3) postfolding high-angle thrusts. Similar thrust types have been defined by R. G. Schmidt in his work to the north and northwest.

Thrusting in the Wood River area, Idaho

Mapping by W. E. Hall, Betty Skipp, J. H. Dover, and J. N. Batchelder showed that allochthonous sheets of the Milligen and Wood River Formations in the Wood River area, Blaine County, Idaho (loc. 3), underlie an area 80 km long in a north-northwest–south-southeast direction and 40 km wide. The Milligen allochthon is composed of a 1,220+ m thick sequence of tightly folded Devonian deep-water siliceous marine clastic rocks that were thrust over a gneissic dome complex in the Pioneer Mountains and the flysch sequence in the Copper Basin Formation (Mississippian). The Wood River allochthon lies on the Milligen allochthon. Geologic studies indicate:

1. The Milligen Formation was tightly folded and emergent before deposition of the Wood River Formation.
2. The Wood River Formation was deformed into broad open folds with north-south axes prior to thrusting.
3. The Milligen and Wood River Formations were thrust toward the northeast. Distal ends are tightly folded and overturned. Stratigraphic separation is at least 3,000 m in the Wood River allochthon with respect to the Milligen. Amount of transport is estimated to be 48 km for the Milligen allochthon and 16 km for the Wood River allochthon.
4. The principal period of thrusting was probably during the Sevier orogeny, although the Milligen allochthon may have been involved in thrusting during the Antler orogeny.

Origin of the Helena Valley

Recent geologic mapping by G. D. Robinson, W. B. Myers, and R. G. Schmidt (USGS) and M. L. Bregman (Univ. of New Mexico) established that Helena Valley in northwestern Montana (loc. 16) is bounded on the northeast by a major northwest-trending normal fault of large displacement named the Helena Valley fault. At the northwestern end of the valley, rocks of the Spokane Formation of the

Ravalli Group of the Belt Supergroup on the southern (valley) side of the fault are dropped down more than 1,000 m against rocks of the Greyson Shale of the Ravalli Group of the Belt Supergroup on the northern side of the fault. To the southeast the fault is mostly concealed by deposits of Tertiary and Quaternary age but is inferred to extend along the base of a low range of hills at the northeastern margin of the valley and along the base of the Spokane Hills that border the valley on the southeast. At the southeastern end of the valley the fault appears to swing south of the Spokane Hills and enter Townsend Valley, perhaps to end against fault structures that border the western side of that basin. Locally, along the base of the Spokane Hills the fault may displace sedimentary beds of Tertiary age downward against rocks of the Belt Supergroup, but this relation has not yet been fully substantiated. The uniform eastward dip of Tertiary beds in the eastern part of the valley suggests that they have been downwarped along the fault. The presence of the Helena Valley fault establishes Helena Valley as a downwarped basin whose structure is broadly similar to that of other downfaulted intermontane basins in western Montana.

Dating a Laramide orogeny, northwestern Wyoming

The relatively short time involved in one major mountain-making event of Laramide age and related episodes of erosion and deposition in Teton County, northwestern Wyoming (loc. 17), can be demonstrated by structural and stratigraphic studies by J. D. Love, pollen determinations by R. H. Tschudy, and a K-Ar age determination by J. D. Obradovich. These data and additional studies in adjacent areas demonstrated the following succession of events, all in Maestrichtian (latest Cretaceous) or late Campanian time:

1. Deposition of 3,600 m of the Harebell Formation, which contains many horizons of fossiliferous marine or brackish-water sedimentary rock and thick quartzite-boulder gold-bearing conglomerates in its upper half. Pollen of early Maestrichtian to late Campanian Age occurs below the conglomerate.
2. Uplift of the Washakie Range, a fold that extends southeastward from Yellowstone Lake for 120 km. The southwestern margin of this fold is bounded by a thrust fault that puts Paleozoic rocks on Upper Cretaceous rocks.
3. Erosion that accompanied and followed the uplifting until the Paleozoic core was exposed. About 7,600 m of rock was removed from the uplift before the next depositional event.
4. Deposition of the Pinyon Conglomerate, 1,220 to 1,525 m thick, laid down on an unconformity across vertical and overturned, eroded strata of the Harebell Formation on the eastern side of Gravel Peak. The basal part of the Pinyon contains a 330-m-thick bed of biotite-rich tuff with a K-Ar age of 67 ± 0.7 m.y. Late Maestrichtian pollen is found about 400 m stratigraphically above the tuff.

Inasmuch as the Maestrichtian Stage began about 70 m.y. ago, all four events must have occurred during a time span of about 3 to 6 m.y.

Influence of Precambrian structural trends in the Rio Grande trough

Preliminary interpretation by L. E. Cordell of aeromagnetic maps of a large part of the Rio Grande trough in central New Mexico (loc. 18) indicated prominent intersecting northeastern and northwestern structural trends in the Precambrian crystalline basement. Precambrian structural grain appears to have influenced the pattern of Cenozoic extensional faulting along the trough.

Pleistocene faulting in the Rio Grande trough

Recent mapping by G. O. Bachman and M. N. Machette demonstrated that faulting of Pleistocene age has displaced the Llano de Albuquerque geomorphic surface near San Acacia south of the confluence of the Rio Puerco with the Rio Grande (loc. 19). The Llano de Albuquerque surface thus extends southward into a local graben farther than previously recognized. Recent K-Ar dating of basalts by R. F. Marvin, H. H. Mehnert, and V. M. Merritt indicated that the Llano de Albuquerque surface is less than 1.1 to 1.3 m.y. old. Therefore, faulting of this surface is much younger than 1 m.y. because extensive caliche had formed on the surface before faulting occurred. Correlation of the Llano de Albuquerque surface is based on mapping and caliche morphology.

GEOTHERMAL RESOURCE STUDIES

Hydrothermal and seismic activity in southwestern Montana

E. C. Robertson found that the hot springs in southwestern Montana occur along three major alinements, one of which, from Gradiner to Marysville, coincides with earthquake epicenters (loc. 20). Fault zones, rather than volcanic flows and igneous

intrusives, seem to control the locations of the hot springs. Ground water circulates to a depth of about 4 km and is heated to 115°C, as estimated from its silica content. The surface temperature and discharge of the springs are constant, and thus a stable supply is provided for resort use; however, the temperatures of the water are too low for the springs to be a geothermal power resource. Increased depth of circulation owning to the head of water at the recently built Canyon Ferry Dam might enhance movement on a nearby fault.

Well drilled in Raft River valley, Idaho, hits hot water

A flow of about 2,000 l/min of water at 147°C was produced from an initial-discovery ERDA well completed in the Raft River valley (loc. 21) early in 1975. The discovery resulted from coordination of integrated geologic (Central Environmental Branch), geophysical (Regional Geophysics Branch), and hydrologic (Water Resources Division) exploration begun a year and a half earlier by the USGS. Drilling of additional boreholes now is in progress.

Known occurrences of thermal water of about 100°C in the southern Raft River basin are located near the intersection of the north-trending faults and the Narrows structure, a northeast-trending linear feature with regional geophysical expression, probably a basement shear, that passes through the southernmost Jim Sage Mountains. Nearly coincident with this structure is a concealed northeast- to east-northeast-trending fault through the Narrows that separates widely different structural styles in the Salt Lake Formation and is expressed by gravity and resistivity. North-trending faults do not cross this structure.

The drill site for RRGE 1 was selected near the intersection of the Narrows structure and the north-trending Bridge fault; the well was predicted to intersect the Bridge fault and produce hot water at or below a depth of 1,400 m; actually, the fault zone and flow of water were encountered between depths of 1,240 and 1,320 m. Seismic and resistivity studies predicted that basement rocks would be encountered in the well at a depth of about 1,600 m; actual depth to basement is 1,375 m. The seismic study showed low-velocity basement under the well site, probably owing to fractured rock, and this proved to be the case.

BASIN AND RANGE PROVINCE

STRATIGRAPHIC AND STRUCTURAL STUDIES

Distribution and economic potential of lower Miocene rocks in the Goldfield Hills, Nevada

Lower Miocene volcanic rocks, mainly trachyandesitic and rhyodacitic flows and tuffs, host the major epithermal precious-metal deposits at Goldfield and Tonopah, Nev. Mapping in the Goldfield quadrangle and the south half of the Mud Lake quadrangle (loc. 1, index map) by R. P. Ashley showed that most of the lower Miocene volcanic rocks in the Goldfield Hills came from a center about 8 km in diameter that occupies the central and topographically highest part of the Goldfield Hills, the Goldfield mining district being at its western edge. On the eastern side of the Goldfield Hills, the rocks of this center interfinger with several flows that may be from another center, perhaps from the Cactus Range, 10 to 20 km farther to the east. A smaller volcanic center, with vents concentrated in an area probably only a few kilometres in diameter, is located about 15 km north-northeast of Goldfield. Only the rocks in the relatively large volcanic center near Goldfield are strongly fractured and extensively altered and thus have good potential for epithermal ore deposits. Rocks on the eastern side of the Goldfields Hills are unaltered except for an altered area of 1 km² that contains a low-grade gold prospect. This prospect, however, is located on the Northern Nellis Bombing and Gunnery Range. The small volcanic center north-northeast of Goldfield shows little fracturing and hydrothermal alteration, and thus potential for epithermal deposits there seems low.

Allocthonous Paleozoic rocks in south-central Idaho

Dominantly allochthonous rocks underlie about 2,500 km² in the Pioneer Mountains region (loc. 2) of south-central Idaho. J. H. Dover, S. W. Hobbs, W. E. Hall, F. S. Simons, C. M. Tschanz, and R. J. Ross, Jr., recognized at least six major thrust plates of Paleozoic sedimentary rocks, each with its own distinctive stratigraphic sequence or structural-metamorphic style. Parautochonous(?) Precambrian gneiss and lower to middle Paleozoic shelf sediments are exposed in only three structural windows. Evidence is accumulating that major structures of Antler (mainly Mississippian) age have been moved into the Pioneer Mountain area on large thrust faults of Mesozoic age. Cumulative crustal shortening of at least some tens of kilometres, and perhaps as much as 150 km, is suggested by reconstruction of early Paleozoic paleofacies and by the extent and intensity of deformation within the allochthons.

New interpretation of the Supai Group of the Grand Canyon, Arizona

Revision of concepts regarding the paleogeography, age, and correlation of the newly described formations that constitute the Supai Group of Pennsylvanian and Permian age was proposed by E. D. McKee. Paleontological data indicate that the Morrowan, Atokan, Virgilian, and Wolfcampian ages are represented in the Supai Group. Isopach lines suggest that the Grand Canyon area (loc. 3) was an embayment that extended eastward from the southern Nevada seaway during much of Pennsylvanian and Early Permian time. Periodically, this embayment also was connected with the Sonoran geosyncline to the southeast, the Paradox basin to the northeast, or both. The complex stratigraphic pattern and the tectonic record of positive and negative elements in the Arizona-Utah region are clarified by the isopach trends and by fossil data.

Geologic hazards in Washoe Valley, Nevada

Long-term geologic hazards in Washoe Valley, Nev. (loc. 4), can result from seismic shaking, flooding, and landsliding. Recent mapping by R. W. Tabor and S. D. Ellen of the very large Slide Mountain landslide, first described by Thompson and White (1964), indicated that the deposit includes at least eight major debris flow events. The earliest debris flow deposits are probably pre-Tahoe in age—that is, older than approximately 60,000 yr—and the youngest deposits may be less than 500 yr old, as indicated by a C^{14} age of 630 ± 200 yr for carbonized wood from beneath the fourth major debris flow mapped in the sequence. The debris flows appear to originate in highly fractured granodiorite distributed in a wide zone along the eastern Sierra Nevada frontal fault system. Considerable hazards may still exist at the mouths of canyons beneath this shattered rock.

Patterns of Cenozoic volcanism in Nevada

A complex pattern of changing volcanism with time was revealed by a synthesis of data from the newly completed Preliminary Geologic Map of Nevada. This synthesis by J. H. Stewart and J. E. Carlson indicates that volcanic rocks ranging in age from 43 to 34 m.y. consist of ash-flow tuffs and andesitic to rhyolitic lava flows in northeastern Nevada and of andesitic to rhyolitic lava flows and sparse ash-flow tuffs in a broad, poorly defined belt trending east-west across central and eastern Nevada between lat 38°30′ and 40°30′. The east-west belt of lava flows is apparently a westward continuation of rocks of similar age and character in Utah. A large percentage of volcanic rocks ranging in age from 34 to 17 m.y. consist of ash-flow tuffs and occur in an irregular belt trending west-northwest and lying between lat 37° and 39° at the eastern border of Nevada and between lat 38° and 40° at the western border. This belt extends into Utah on the east and into the Sierra Nevada region of California on the west. Volcanic rocks less than 17 m.y. old are extensively exposed in northern, western, and southern Nevada. Of particular importance in this age bracket are rocks consisting dominantly of ash-flow tuffs that are exposed in an east-west belt between lat 36°30′ and 37°30′. This belt extends into the Sierra Nevada region of California. It is parallel to and overlaps the southern margin of the ash-flow tuff belt defined by rocks 34 to 17 m.y. old. One component of the complex pattern of Cenozoic volcanism appears to be a southward migration of volcanic activity from the belt of 43- to 34-m.y.-old rocks in central and eastern Nevada to the belt of rocks 17 m.y. old and younger in southern Nevada.

Tertiary sediments in eastern Elko County, Nevada

Examination by R. R. Coats of Tertiary sediments in Elko County, Nev. (loc. 5), east of the longitude

of the Ruby Range, showed that most of them contain a large component of silicic volcanic debris, which suggests that they are younger than the Eocene clastic and limy sediments of the Carlin-Pinyon Range area, found by J. P. Smith and K. B. Ketner to contain little or no volcanic debris. Most of the Tertiary sediments in eastern Elko County are directly underlain by poorly consolidated, nearly horizontal tuffaceous sediments, presumably equivalent to the Humboldt Formation of Miocene age, but substantial areas of deformed and lithified tuffs and tuffaceous sediments, presumably older, are also present.

Age of the former Leach Formation in Nevada

Conodonts collected in the East Range of Nevada by D. H. Whitebread from the former Leach Formation were identified as Ordovician in age by J. W. Huddle and thus further support correlation of much of the "Leach" with the Valmy Formation of north-central Nevada. The section containing the conodont-bearing limestones was tentatively included in the Havallah sequence of Pennsylvanian to Permian age by Stewart and Carlson (1974a). A thrust fault within the former Leach Formation separates this section from a quartzite-bearing unit recognized earlier to be equivalent to part of the Valmy Formation. The former Leach Formation is not entirely of Ordovician age, however, because locally some rocks formerly included in the Leach are now recognized as part of the Havallah sequence.

Possible new member of Oquirrh Formation in central Utah

Stratigraphic studies by H. T. Morris in two areas in the southernmost part of the East Tintic Mountains (loc. 7) in central Utah disclosed a possible new member of the Oquirrh Formation that is younger than any rocks exposed in the type area of the formation in the Oquirrh Mountains. This sequence of rocks is about 1,675 m thick and contains fusilinids of Virgilian and Wolfcampian age. It is comparable to beds in the uppermost part of the Oquirrh Formation in the southern Wasatch Mountains and is overlain by the Diamond Creek Sandstone.

Characteristics of active faults in the Nevada seismic zone

Investigation by R. C. Bucknam of the chemical and petrographic characteristics of a volcanic ash layer that is widespread in the near-surface alluvium of Mineral County, Nev. (loc. 8), indicated that it probably was erupted from Mono Craters, Calif. Several C^{14} dates of organic material associated with the ash indicate an age of about 1,100 yr. Locally, the ash represents a useful stratigraphic marker horizon, and it serves to date the prominent fault scarp in alluvium along the Wassuk Range south of Hawthorne, Nev., at more than 1,100 yr old.

GEOCHEMICAL AND GEOCHRONOLOGICAL STUDIES

Geochemical anomalies in the Peloncillo Mountains, New Mexico

Geochemical maps showing the distribution of Cu, Pb, Zn, Bi, W, Mo, and Ag in the central Peloncillo Mountains, N. Mex. (loc. 9), were compiled by A. K. Armstrong, R. B. Carten, M. L. Silberman, and V. R. Todd. Concentrations of anomalous copper, lead, zinc, and silver occur within garnet-bearing metamorphic rocks adjacent to quartz monzonite porphyry, felsite, and latite porphyry dikes of middle Oligocene age emplaced along the northwest-trending Johnny Bull fault and nearby parallel faults and along the northeast-trending Preacher Mountain fault where it intersects several northwest-trending faults. Lesser, but still anomalous, concentrations of metals occur in the dike rocks. Anomalous concentrations of copper, lead, zinc, and silver are also associated with lead-zinc replacement deposits near McGhee Peak that are controlled by northeast-trending felsite dikes branching from a larger quartz monzonite sill. Farther east, an anomalous zone of lead, zinc, and silver at the Carbonate Hill mine occurs within and adjacent to another large felsite dike. At Granite Gap, anomalous concentrations of base metals and silver are in small, largely oxidized, hydrothermal sulfide veins in fractured limestone. Smaller areas of anomalous copper, lead, and zinc appear north of Granite Gap, where quartz monzonite porphyry and latite porphyry dikes intruded and metamorphosed the sedimentary rocks.

Trace-element ratio maps indicate a well-defined zoning pattern with a relative enrichment of copper along and near the Johnny Bull fault in the McGhee Peak area and a relative enrichment of lead, zinc, and silver farther east towards the Carbonate Hill mine. Similar zoning patterns are found elsewhere along the Johnny Bull and Preacher Mountain faults.

Spatial association of the mineral deposits with the quartz monzonite and latite porphyries and the presence of a small outcrop of mineralized quartz monzonite porphyry north of McGhee Peak suggest that mineralization is related to the middle Oligocene igneous event.

Fission tracks record uplift of Wasatch Range, Utah

The time and rate of uplift of the Wasatch Range (loc. 10), relative to the adjacent basin of the Great Salt Lake, are recorded by fission-track dates, determined by C. W. Naeser, of apatites from Precambrian gneissic rocks exposed in the area near Ogden, Utah, that is being mapped by M. D. Crittenden, Jr., and M. L. Sorensen. Ages of apatites from the Bountiful Peak area range from 9.6±1.9 m.y., collected at 9,334 km, to 72.6±14.5 m.y. at 13,084 km. Apatites collected at intermediate elevations have yielded intermediate ages. Apatites collected in Weber Canyon, along an approximately level line, range in age from 5.1±1.0 m.y. at the Wasatch fault to 18.2±3.6 m.y. near the easternmost exposures of Precambrian rocks near Mountain Green, Utah. This eastward increase of fission-track ages implies a pattern of uplift in which the range has risen along its western side and has tended to pivot along its eastern side. Two samples of apatites from Little Mountain at the edge of Great Salt Lake west of Ogden gave fission-track ages of 65±6 m.y. and 73±7 m.y.

Experimental data indicate that fission tracks in apatite are annealed by heating to 100°C for periods on the order of 1 m.y. These data cannot be interpreted to yield a single specific cooling history because the annealing process is dependent on both time and temperature; however, it is reasonable to assume that the apatite dates record approximately the time that the rocks passed through the 100°C isotherm. When typical geothermal gradients are assumed, it can be inferred that the rocks lay at a depth of about 3,000 m at approximately the times indicated. On that basis, the rocks within the range are assumed to have been uplifted on the order of 3,000 m in 7 to 9 m.y., or 330 to 430 m/m.y. In contrast, the rocks of the block beneath Great Salt Lake have not been subjected to that degree of heating or burial since approximately 70 m.y. ago.

Age of basaltic dikes in the Roberts Creek Mountains, Nevada

Mapping by E. H. McKee showed that northwest-trending dikes of basaltic composition make up about 15 percent of the surface outcrops in the northern part of the Roberts Creek Mountains, Nev. (loc. 11). The anastomosing network of dikes is expressed as a strong aeromagnetic belt in line with outcrops of basalt flows exposed to the northwest. The dikes yield a K-Ar age of about 16 m.y., which is the same as the age of basalt flows to the northwest. These basalts represent the oldest Cenozoic basalts in this part of the Great Basin. The presence of basalt along the belt suggests some sort of major rift features related to the inception of Basin and Range tectonism.

Submarine-sediment gravity flows

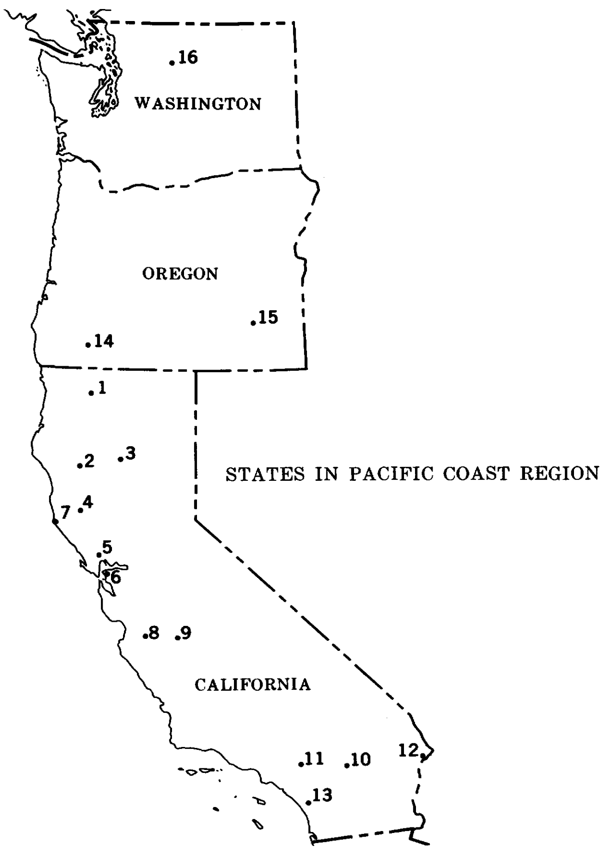
H. E. Cook and M. E. Taylor (1975) found that the Cambrian and Ordovician rocks in the Basin and Range province consist of basinal sediments in central Nevada and shallow-water platform and broad tideflat sediments in eastern Nevada. A wide variety of allochthonous carbonate debris deposits occurs in the basinal facies. This debris was transported basinward by submarine-sediment gravity-flow mechanisms from upslope basinal and shoal-water carbonate environments to the east. Fossil assemblages in these allochthonous deposits are related to the North American province, whereas fossil assemblages in the in-place basinal lime mudstones and wackestones bear no similarity, being related instead to the Asian faunal province. One implication of large-scale importance in reconstructing the geologic history of the Cordilleran continental margin is that the in-place basinal sediments containing the Asian fauna are not simply part of a hypothetical crustal fragment left behind after an Asian plate and a North American plate collided and later separated. Rather, these interbedded divergent faunas reflect fluctuations of the boundary between two distinct marine environments: the North American continental platform and adjacent ocean basin. Potentially similar relationships between other ancient faunal provinces should be studied to avoid misuse of faunal data in paleogeographical reconstructions of lithospheric plates.

PACIFIC COAST REGION

CALIFORNIA

Blueschist, quartz diorite, and quartz keratophyre in eastern Klamath Mountains

Geologic mapping by P. E. Hotz in the McConaugby Gulch and upper Moffett Creek areas, northeastern Etna and northwestern China Mountain quadrangles (loc. 1, index map), eastern Klamath Mountains, Calif., revealed a belt of mafic and siliceous phyllites and semischists and lawsonite-bearing blueschist that is exposed in a window of the Mallethead thrust. The Mallethead thrust brings lower Paleozoic(?) phyllites over sedimentary rocks of Ordovician to Devonian age. Altered, brecciated quartz



diorite and quartz keratophyre occur in conjunction with the phyllites and semischists. The quartz diorite is probably the same as Lower Ordovician plutonic rocks in the Gazelle-Callahan area to the east (Potter, 1973; Rohr and Potter, 1973). The phyllites, semischists, and blueschist have not been dated. They are 20 to 24 km south and southeast of a previously reported (Hotz, 1973) belt of blueschist between serpentinite and an upper Paleozoic greenstone-chert assemblage.

Magnetic anomalies may define former subduction zones

Interpretation of regional aeromagnetic data in the Coast Ranges (loc. 2) of northern California by Andrew Griscom, M. C. Blake, Jr., and Isidore Zietz showed that broad low-amplitude magnetic anomalies over the Franciscan assemblage form lineaments up to 150 km long along which are found small serpentinite masses. It appears likely that the anomalies may define mélange units and that detailed aeromagnetic data may provide a way to map such units more accurately.

The same investigators also noted two linear magnetic anomalies near Eureka, Calif., that trend northeast and are interpreted to be oceanic magnetic stripes within the subducted Gorda plate beneath the Franciscan assemblage. The anomalies are at a depth of approximately 8 km below the surface and are 55 km east of the inferred location of the outcropping subduction zone at the base of the continental slope.

Paleozoic and Mesozoic contact in northern Sierra Nevada

Metavolcanic rocks exposed in the southwestern part of the Berry Creek quadrangle (loc. 3), according to Anna Hietanen, rest on Paleozoic (Permian?) metasedimentary rocks and are continuous with the Mesozoic metavolcanic rocks to the south. Chemically, these rocks are similar to the Franklin Canyon Formation (Devonian?) in the Bucks Lake and American House quadrangles, but they are less deformed and less thoroughly recrystallized. In many outcrops, phenocrysts consisting of augite in metabasalt, of plagioclase in meta-andesite and metadacite, and of quartz in meta-sodarhyolite are well preserved, undeformed, and have sharply defined crystal faces. Outside the contact aureole of the Bald Rock pluton, the ground mass is poorly recrystallized. Tiny crystals of epidote, clinozoisite, amphibole, and chlorite can be recognized only under a high-powered lens. Fragments in volcanic ejecta and amygdules are undeformed, in contrast to elongate shapes of bombs, lapilli, and amygdules in most Paleozoic rocks.

Structure and metamorphism of Franciscan rocks and their relation to ophiolite in The Geysers steam field, California

An investigation of the structure of upper Mesozoic rocks that underlie The Geysers steam field of northern California (loc. 4) by R. J. McLaughlin revealed that these rocks form a 6- to 8-km-wide southeastward-plunging antiform. The antiform is flanked on the northeast and southwest by major northwest-trending steeply dipping fault zones, and its core is composed of complexly deformed and metamorphosed marine sedimentary and volcanic rocks of the Franciscan assemblage. Metamorphosed Franciscan sandstones in the core of the antiform exhibit a progressively higher degree of textural reconstitution in the direction of the structurally highest rocks, and the sequential upward appearance of the metamorphic minerals pumpellyite, lawsonite, sodic amphibole, and jadeitic pyroxene indicates that structurally higher sandstones were subjected to increasingly higher presures during their metamorphism.

Ultramafic and mafic intrusive and extrusive rocks interpreted to represent oceanic crust (ophiolite)

overlie the Franciscan assemblage, and the lower part of this ophiolite is in part sheared into the underlying Franciscan rocks. Ophiolite in the southeastern part of the map area, near Mount St. Helena, is offset right laterally along the N. 40°–50° W.-trending Geyser Peak fault a minimum of 8 to 10 km from ophiolite exposed at Geyser Peak and Black Mountain on the southwestern side of the fault. Another steeply dipping strike-slip fault to the southwest of Geyser Peak and subparallel to the Geyser Peak fault offsets upper Tertiary (Pliocene?) nonmarine strata and may be active.

Unconformity with the Sonoma Volcanics

Recent work by K. F. Fox, Jr., documented the existence of a major unconformity within the Sonoma Volcanics (Pliocene). These rocks form a northwest-trending volcanic field 88.5 km long and 32 km wide located in the northern part of the San Francisco Bay area, Calif. (loc. 5).

Rocks above the unconformity consist of a thick sequence of ash flows (many of which are welded or partially welded) and tuff, tuff-breccia, agglomerate, and rhyolite that are locally capped by basalt flows. These rocks form the northern half of the field and, on the basis of dating by earlier workers, are about 3 to 4 m.y. old. They have been collectively referred to as the "Sonoma Tuff."

Rocks below the unconformity form the southern half of the field. They are geographically divided by intervening alluvium-floored tectonic valleys into three linear, northwest-trending blocks. They consist chiefly of basalt or andesite, with subordinate interlayered ash flows and rhyolite flows, in contrast to the predominantly tuffaceous rocks of the younger part of the field to the north.

Remnants of redwood forests that grew on ash flows directly above the unconformity at the base of the Sonoma Volcanics are preserved at the locally famous Petrified Forest.

The structure and stratigraphy of the volcanic rocks are of interest to bay area environmental geologists because the field overlaps four important northwest-trending fault systems: the Green Valley, Maacama-Carneros, Healdsburg-Rodgers Creek, and Tolay faults.

Amino-acid dating of marine terraces

The lack of a widely applicable technique for dating geologic materials in the 40,000- to 1,000,000-yr.-B.P. range has been a serious stumbling block in many aspects of Quaternary research. In the past 5 yr, research by P. E. Hare (Carnegie Institute of Washington), John Wehmiller (Univ. of Delaware), Etta Peterson and K. A. Kvenvolden (Ames Research Center), and J. L. Bada (Scripps Institute of Oceanography) has demonstrated that racemization ratios of amino acids in some fossil materials can be used to estimate geologic ages in this time range. A joint project involving scientists from Ames Research Center and the USGS was set up in late 1973 to investigate the reliability and applicability of this potentially useful dating technique. C. M. Wentworth, D. P. Adam, E. J. Helley, and K. R. Lajoie (USGS) supplied known-age samples of wood, bone, tooth, and shell for an initial feasibility study. Racemization analyses of seven amino acids in these samples by Peterson and Kvenvolden yielded encouraging results. In general, the racemization ratios increased with the age of the sample, but several glaring discrepancies existed, and it was apparent that data from different types of samples could not be directly compared. A more tightly controlled experiment was set up to remove some of the uncertainty in the first set of analyses.

Lajoie and R. H. Wright selected a suite of fossil gastropod and pelecypod shells from emergent marine terraces between San Francisco and San Diego to investigate (1) variability among different taxa, (2) variability among numerous specimens of the same species from the same outcrop, (3) variability in one species from the lowest emergent terrace over a broad range in latitude, and (4) systematic variation with age in one species going up a flight of terraces. Peterson's initial results on this second suite of samples indicated that thick-shelled aragonitic mollusk shells yield the most reproducible and reasonable results.

Analyses by Wehmiller and Peterson on an expanded suite of pelecypod samples from the emergent marine terraces confirmed that racemization ratios of amino acids from gastropods are significantly different and far less consistent than those of amino acids from pelecypods of the same age. These differences are due in part to contamination of the more fragile gastropod shells analyzed and in part to a significant taxonomic effect on racemization rates.

The geologic correlations and age estimates derived from the amino-acid data provide critical information for other studies such as coastal tectonics recorded in emergent marine terrace deformation.

Racemization ratios for eight samples of pelecypods from the lowest terrace in the Santa Cruz area

have a reproducibility of ±10 percent, which is similar to values obtained from multiple analyses on fossils from several localities along the southern California coast.

Preliminary results of these feasibility studies indicate that racemization ratios of fossil mollusks will be very useful for correlating and dating late Pleistocene events. Tentative geologic conclusions can be drawn from the results obtained to date. Similar racemization ratios in fossils from the first (lowest) emergent terrace at Año Nuevo, Santa Cruz, Cayucos, Newport Beach, and Torrey Pines and from the second terrace on San Nicolas Island correlate these widely separated wave-cut features. The estimated amino-acid age of 140,000±50,000 yr for this group of terrace remnants is in close agreement with U-series coral ages of 130,000±30,000 yr for the Cayucos terrace (Veeh and Valentine, 1967) and >87,000±12,000 but <120,000±20,000 yr for the second terrace on San Nicolas Island (Veeh and Valentine, 1967). Slightly higher mean racemization ratios in samples from southern California are interpreted to be the effect of slightly higher temperatures (due to lower latitude) during diagenesis.

Different racemization ratios in fossils from the first terraces at Goleta and Huntington Beach indicate that these two terrace remnants do not correlate with those listed above. Slightly lower ratios at Goleta yield an estimated age of 60,000±20,000 yr, and significantly higher ratios at Huntington Beach yield an estimated age of 300,000±50,000 yr.

Racemization ratios in fossils from the fifth (122 m) and the tenth (244 m) terraces on San Nicolas Island are successively higher than those at Huntington Beach and yield estimated ages of 0.4 m.y. and 0.6 m.y., respectively, which agree with the >200,000-yr U-series coral age of the ninth (221 m) terrace (Valentine and Veeh, 1969).

Kinetic studies and several tightly controlled field experiments are presently being organized to attempt to reduce the age-estimate uncertainties and extend the range of the technique to late Pliocene time.

Age of San Francisco Bay

E. J. Helley and B. F. Atwater finished radiocarbon dating of the Holocene marine transgression of San Francisco Bay (loc. 6). Modern estuarine water first entered the Golden Gate and reached the vicinity of the proposed southern crossing between 9,600 and 9,300 radiocarbon years ago. The San Mateo-Hayward crossing was reached at 8,400 yr B.P., and the vicinity of the Dumbarton Bridge was reached at about 6,200 yr B.P. The environments of deposition of the radiocarbon dated cores are being analyzed to allow determination of the tidal level relative to the radiocarbon dates. This analysis will allow construction of a sea-level curve for San Francisco Bay.

New northeast-trending active fault discovered in San Francisco Bay region

Field studies by D. G. Herd indicated that the Las Positas fault is a zone of steeply dipping imbricate fractures extending from the southeast corner of Livermore Valley southwestward 14 km to near the San Antonio Reservoir in La Costa Valley. Pliocene and Pleistocene Livermore gravels and Pleistocene and Holocene alluvium northeast of Arroyo Valle are downthrown on the northern side of the fault. Southwest of Arroyo Valle, Tertiary marine sediments are in fault contact with northeast-dipping Livermore gravels.

Sediments of the Tassajara Formation (Pliocene or Pleistocene) and Livermore gravels were deformed during the late Pliocene or early Pleistocene into a series of northwest-trending folds in Livermore Valley. The units apparently tore with a scissors effect at depth along the fault from the Jurassic, Cretaceous, and Tertiary rocks of the Diablo Range. Recent seismic activity and displacements in upper Holocene alluvium indicate that the fault is still active.

Landslides are expensive

At least 335 landslides have damaged manmade structures in Alameda County, Calif. (loc. 6), from 1940 to 1971, according to a study by T. H. Nilsen, F. A. Taylor, and E. E. Brabb (1975). About 85 percent occur on slopes greater than 15 percent. Over $5 million worth of damage was caused by landsliding during just one rainy season alone, 1968–69. This cost averages to about $400 per developed acre of land on slopes greater than 15 percent, or about $100 per dwelling unit.

Chemical correlation of upper Cenozoic tuffs in California

A. M. Sarna-Wojcicki and others have been working on a tephrochronology project, the purpose of which is to correlate upper Cenozoic deposits in California. X-ray-fluorescence analyses of trace and minor elements are being made by B. P. Fabbi (USGS), neutron activation analyses are being run by Harry Bowman (Lawrence Radiation Labora-

tory), and fission-track dating is being done by D. G. Herd (USGS). Noteworthy preliminary results to date include:

1. The tuff in the type section of the Merced Formation south of San Francisco has been correlated by means of trace- and minor-element chemistry with other tuffs within the San Francisco Bay area, as well as with a tuff 320 km to the north in the southern Cascade Range near Mount Lassen pumice ash flow near Mineral, Calif. A recent zircon fission-track date by C. W. Naeser gives 1.1±0.4 m.y. on the type Merced tuff, confirming the chemical correlation with the pumice ash flow near Mineral, Calif. (K-Ar age of 1.1±0.5 m.y.). The age of this tuff is important not only because it gives a maximum age for faulting and folding of Pleistocene deposits but also because the presence of this water-transported tuff in the Merced Formation dates the inception of Great Valley drainage across the central Coast Ranges in the vicinity of the San Francisco Bay area and thus provides an important piece of information on the paleogeography of the bay area and the Great Valley.
2. Recently, computer analyses have been made of chemical data on tephra and other silicic volcanic rocks from upper Cenozoic volcanic source areas in California, as well as on widespread ashes and tuffs deposited in sedimentary basins. The purpose of this project is to identify the volcanic provinces from which ashes and tuffs were erupted. In the case of water-transported ashes and tuffs, this kind of information may also provide paleogeographic evidence (as in the preceding paragraph). Two different computer programs have been used to determine the degree of similarity between silicic volcanic rocks. One program calculates a similarity coefficient for each sample pair in the group. The other is a cluster analysis with dendrogram, which clusters samples into groups of progressively greater difference by means of the distance function or the correlation coefficient. Preliminary results of this study indicate that provincial chemical similarities exist between the pumice ash at Friant, the Bishop Tuff, Mono Craters, and Mono Glass Mountain; all the above differ markedly from the Inyo Craters. A thick, water-laid tuff in the Purisima Formation (Pliocene) of Santa Cruz Mountains, however, has strong provincial similarities with tephra of the southern Cascade Range. This tuff was probably transported by streams southward along the ancestral drainage outlet of the Great Valley to a marine basin west of the San Andreas fault and was subsequently shifted northwestward at least 180 km. Results of trace- and minor-element analyses on another thick, water-laid tuff within the San Joaquin Formation (Pliocene) in the Kettleman Hills indicate that it is correlative with the Nomlaki Tuff Member of the Tehama Formation (K-Ar age of 3.4±0.4 m.y.) at Gas Point in northwestern Sacramento Valley, about 540 km to the northwest. If further verified, this correlation would further support the conclusion that through late Pliocene time the drainage in the Great Valley was southerly, to a southwestern connection with the ocean.
3. Samples of three different tuffs were obtained from a core hole drilled by Earth Science Associates for the Pacific Gas and Electric Company, in a foundation investigation study for a proposed nuclear reactor site at Collinsville, in the delta country just west of the Montezuma Hills. Preliminary results of neutron activation analysis indicate that the middle tuff is correlative with the Lawlor Tuff north of Mount Diablo, previously K-Ar dated at 4.0±0.2 m.y. Correlatives of the other two tuffs have not as yet been recognized.
4. Preliminary results of neutron activation analyses indicate that one of the major ash-flow tuffs in the Petrified Forest area of the Sonoma Volcanics, central Coast Ranges, is correlative with a tuff in the Pliocene Rio Dell Formation of Ogle (1953) at Cape Mendocino, near Ferndale. If further verified, this correlation would be over a distance of about 250 km. The tuff at the Petrified Forest has been K-Ar dated at 3.4 m.y., and this correlation would thus date the tuff in the Rio Dell Formation.

Early Tertiary history of San Andreas fault

Paleogeographic reconstructions of lower Tertiary deposits in the Gualala area (loc. 7), Santa Cruz Mountains, and northern Gabilan Range by T. H. Nilsen (USGS) and T. R. Simoni, Jr., and M. H. Link (L.A. Harbor College), together with those of the central Diablo Range, Temblor Range, and San Emigdio Mountains, indicate the presence of an elongate continental borderland in Paleogene California

that was emplaced by pre-Eocene right-lateral slip along a proto-San Andreas fault. Large deep-sea fans were deposited in isolated basins that were located within and adjacent to the borderland. These basins developed by extensional tectonic activity characteristic of continental transform faults. The modern San Andreas fault came into existence during Miocene time and has been responsible for a total of about 305 km of right-lateral offset.

Evolution of Panoche Valley

Field studies by T. W. Dibblee, Jr., indicated that the Panoche Valley (loc. 8), about 70 km northwest of Coalinga, is underlain by alluvium and Pliocene and Pleistocene alluvial sediments. These presumably rest on the beveled surface of the very thick Cretaceous "Great Valley sequence" that overlies the Franciscan complex of the Diablo Range to the west and dips eastward through the Panoche Hils toward the San Joaquin Valley to the northeast and southward under the mountains to the south. Remnants of the alluvial sediments on the crests of the Panoche Hills, where they contain gypsiferous caliche of economic value, indicate that these hills as well as the Panoche Valley became part of the San Joaquin Valley in Pliocene and Pleistocene time. Since that time, the Panoche Hills were elevated, partly on the Ortigalita fault system, to isolate Panoche Valley from the San Joaquin Valley, and the mountains to the south were elevated anticlinally and in part by thrusting toward Panoche Valley.

Gravity changes, Pixley subsidence area

A repeat gravity survey by W. F. Hanna in a 13× 20-km region of the Pixley, Calif. (loc. 9), subsidence area indicates that tide-corrected changes in observed gravity during the period 1969–74 are associated more with subsurface changes of mass than with changes in surface elevation. The areally systematic gravity changes, which range from -0.04 to $+0.17$ mGal, show very little correlation with subsidence patterns but remarkably strong correlation with the subsurface featheredge of the Corcoran Clay Member of the Tulare Formation, a major confining unit of underground aquifers. The main cause of inferred increase of mass beneath the western part of the area may be a watering of the unconfined zone above the Corcoran, although elastic volumetric effects in the underlying confined zone cannot be dismissed. Refined interpretations by Hanna and B. E. Lofgren will incorporate subsurface compaction and water table data. Results are expected to apply to repeat gravity surveys made elsewhere to detect elevation changes associated with tectonic activity or with sediment compaction.

Cooling history of the eastern Transverse Ranges

About 110 ^{40}K–^{40}Ar ratios were determined for minerals from granitic rocks of the eastern Transverse Ranges and southern Mojave Desert (loc. 10) by F. K. Miller and D. M. Morton. These ratios yield ages that range from 55 m.y. to 122 m.y. Most coexisting mineral pairs yield concordant ages, but three lines of evidence suggest that none of the dates is an emplacement age: (1) rocks known to be Precambrian yield Cretaceous ages on the basis of concordant K-Ar dates from coexisting minerals; (2) rocks from different parts of a single pluton yield different apparent ages; and (3) biotite ages can be contoured in a regular manner; the contours in no way relate to the shapes of individual plutons.

The configuration of the biotite age contours is interpreted to reflect the cooling history of the region. As a result, K-Ar ages from any rock in the eastern Transverse Ranges or southern Mojave Desert have little relation to age of emplacement, and the age yielded by any sample is mainly a function of its geographic position.

The trend of the biotite age contours in the southern Mojave parallels the northwestern structural grain of the region. Northwest-trending biotite age contours also exist in the northern part of the San Bernardino Mountains but appear to be offset from those on the Mojave by a system of reverse faults on the northern side of the range. The trend of less well defined age contours in the southern part of the San Bernardino Mountains appears to be east-west, parallel to the structural grain of the Transverse Ranges.

Biotite age contours in the southern part of the eastern San Gabriel Mountains appear to trend about east-west, but enough data points are not available as yet to contour the apparent ages unequivocably.

Ground fissuring in part of the San Jacinto Valley, southern California

According to D. M. Morton, ground fissuring is a surface manifestation of subsidence in the San Jacinto Valley (loc. 11), southern California. The subsidence is occurring in a deep alluvial-filled graben located between the Casa Loma and San Jacinto faults. Tectonic subsidence of the graben is estimated at 0.3 to 0.6 cm/yr. Subsidence due to ground-water

withdrawal is estimated at a maximum of 3.5 cm/yr. Ground fissuring is occurring primarily on the western side of a closed depression in the graben. The area of ground fissuring has expanded from 1 km^2 in 1953 to 12 km^2 in 1974. Individual fissures have attained lengths of 850 m. The ultimate extent of the ground fissures is not known.

Cenozoic tectonics of eastern Mojave Desert

Work in the Parker, Ariz., area and adjacent California (loc. 12) by W. J. Carr and D. D. Dickey indicated the virtual absence of active faults. The youngest surficial fault activity appears to be of early Pleistocene age. Absence of active faulting is supported by a lack of low-level seismicity and by the subdued geomorphic expression of the basins and ranges. The Tertiary structural, volcanic, and sedimentary records suggest that major faulting in the region ended about 14 m.y. ago. The Cenozoic structure of the area is one of persistent southwest-dipping Tertiary rocks repeated by low to moderate northeast-dipping faults. In the Whipple Mountains these faults shoal out to join a major low-angle fault of Tertiary age that involves Tertiary and Precambrian rocks. These structures can be interpreted as having formed in an episode of major regional strike-slip faulting.

Mylonitic rocks in the Peninsular Ranges batholith west of the Elsinore fault zone

Preliminary results of detailed geologic mapping in the Peninsular Ranges batholith in the Laguna Mountains of eastern San Diego County (loc. 13) by V. R. Todd indicated the existence of a zone (or zones) of mylonitic rocks that roughly parallels the north-south to northwest regional structural grain in this part of the batholith. Rocks showing varying degrees of dynamic metamorphism have been found in a zone at least 24 km long and 12 km wide. Textures seen thus far range from augen gneiss, in which extensive recrystallization has accompanied cataclasis, to ultramylonite. Mylonitization occurs in plutonic rocks and in metaigneous(?) gneiss and schist. The intensity of cataclasis appears to vary in an irregular manner within a given area of mylonitic rock. The mylonitic rocks are significant because younger crush zones appear to follow zones of mylonitization. At least one of these crush zones is the trace of a fault with relatively young topographic expression. As far as is known, this occurrence of mylonite is the first reported in crystalline rocks west of the Elsinore fault. Further field studies should determine the full extent of these rocks and their relationship, if any, to mylonites east of the Elsinore fault.

OREGON

New breakdown of Applegate Group in southwestern Oregon

N. J Page reported that within the southern part of the Medford 2° quadrangle (loc. 14), the Applegate Group of Late(?) Triassic age can be broken into five mappable units separated by tectonic boundaries: (1) meta-andesitic to metadacitic flows and tuffs interlayered with argillites, (2) metasedimentary rocks with local lenses of metavolcanic rocks, (3) metasedimentary rocks containing an abundance of quartz-rich sedimentary rocks, (4) mélange consisting dominantly of serpentinite and metasedimentary rocks, and (5) mélange consisting dominantly of serpentinite and metabasaltic rocks. The areal distribution of these rock units correlates well with the distribution of aeromagnetic highs (metavolcanic rocks) and lows (metasedimentary rocks). The highs show some correlation with the broad distribution of known mineral occurrences.

Complex terrane along northwestern border of Josephine peridotite in southwestern Oregon

Detailed studies by R. A. Loney and G. R. Himmelberg along the northwestern border of the Josephine ultramafic complex in southwestern Oregon (loc. 15) showed that the Vulcan Peak alpine-type peridotite is a harzburgite body that has been intensely deformed and recrystallized at high temperatures in the upper mantle before being thrust at low temperatures against the high-grade metamorphic and igneous complex to the north and then against the low-grade Dothan Formation to the west (Himmelberg and Loney, 1973).

The complex consists of intensely folded amphibolite and ultramafic rocks of unknown age that are intruded by hornblende gabbro of Late Jurassic age. The oldest rocks are the amphibolites, which are thinly foliated rocks of mainly andesitic composition that have undergone metamorphism of the amphibolite facies. The less deformed, younger ultramafic rocks consist of intensely recrystallized clinopyroxenite, wehrlite, and dunite that contain relict cumulate textures. Such clinopyroxene-bearing cumulates are lacking in the Vulcan Peak peridotite and seem also to be lacking in the Josephine ultramafic complex as a whole. They do resemble basal sections of cumulate gabbros in some ophiolite complexes, but the presence of amphibolite negates this resem-

blance, and the fragmentation by the intrusive gabbro makes further comparison difficult. The hornblende gabbro commonly shows a marked gneissic magmatic flow structure; its chemical composition is similar to that of tholeiitic basalt.

WASHINGTON

New age determinations from the Okanogan Range

New K-Ar age determinations from six localities representing four plutons that occupy an area of 1,300 km^2 or more in the central Okanogan Range (loc. 16) were recently obtained by C. D. Rinehart and K. F. Fox, Jr., and showed minimum ages of about 81 to 108 m.y. Discordance in the ages of mineral pairs is least (3 percent) in the youngest pluton and greatest (13 percent) in the oldest. Three of the plutons are partly nested and successively younger inward, and their relative ages are well established from field relations. The youngest (81 m.y.) of the three plutons is also the youngest thus far dated in the range. Four mineral pairs from the older plutons show much overlap, although the oldest age (108 m.y.) is also from the pluton whose intrusive relations show it to be the oldest. Of the ages of the three plutons, those of both the oldest and the youngest corroborate fairly well the radiometric ages of these units reported by Menzer (1970, p. 576, 577), although he reported a Rb-Sr age of 129 m.y. from the intermediate unit. Farther north, a single biotite age of 98 m.y. was obtained from a sample of the Cathedral batholith, agreeing well with a 94-m.y. age reported by Hawkins (1968, p. 1789).

Thus the number of plutons known to be dated in the Okanogan Range is increased to nine; the oldest —the Loomis (Rinehart and Fox, 1972, p. 44–46)— is 194 m.y.

Intracanyon flows of Yakima Basalt along the Snake River, southeastern Washington

Isolated remnants of at least five intracanyon basalt flows occur along the Snake River for 160 km between Devils Canyon and a point 12 km upriver from Asotin, Wash. These flows partly fill an ancestral Snake River Canyon eroded more than 300 m into the Yakima Basalt. The flows were once considered early Pleistocene in age, but D. A. Swanson and T. L. Wright (USGS) and the late Richard Clem (Whitman College) interpreted them to be in the upper part of the Yakima Basalt on the basis of K-Ar dates and similar chemical and petrographic characteristics. The youngest flow extends eastward from Devils Canyon for at least 85 km. The two flows of intermediate age occur along most of the 160-km distance and are correlated with the Pomona and Elephant Mountain Flows of the Yakima on the basis of chemistry, petrography, paleomagnetic polarity, and the presence of a distinctive vitric tuff that underlies and forms a peperite with the Pomona. The oldest flow and the least known flow may extend from Devils Canyon upriver for at least 50 km and 150 km, respectively. Sources for the flows are unknown, but unusually thick flow remnants near Asotin, interpreted as lava dams that blocked the ancestral Snake River Canyon, suggest proximity to vent areas for the Pomona and Elephant Mountain Flows. Imbricated gravel of metamorphic, plutonic, and basaltic derivation underlies several remnants and indicates a westward gradient for the ancestral Snake River Canyon. Canyon cutting began about 13 to 15 m.y. ago during an eventful period of regional subsidence, changing magma chemistry, and decreasing rate of magma production. The intracanyon flows were erupted during several successive stages of canyon development, after most of the regional subsidence but before significant deformation of the Lewiston downwarp and other folds east of the Saddle Mountains.

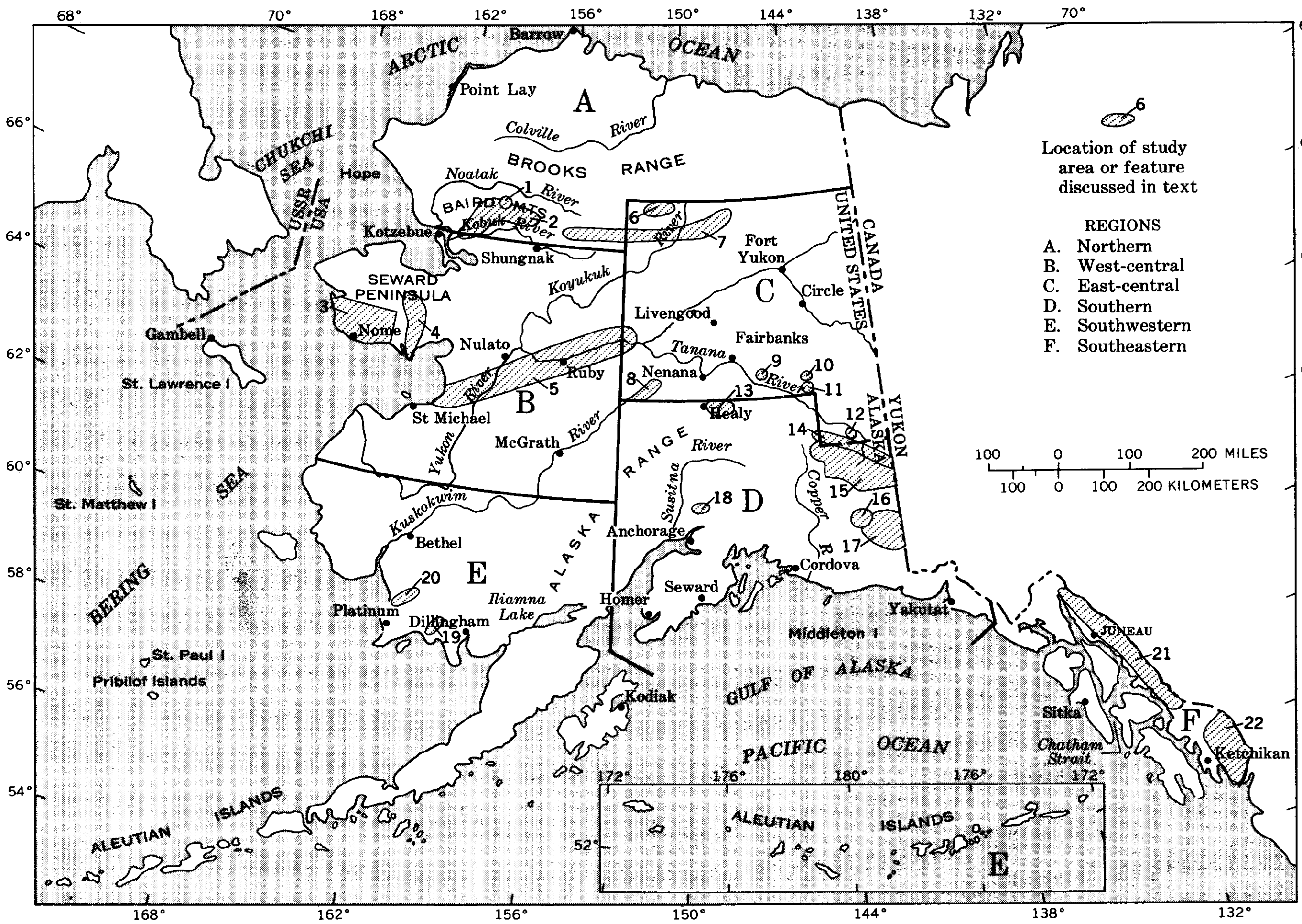
ALASKA

Significant new scientific and economic geologic information has resulted from many field and topical investigations in Alaska during the past year. Discussions of the findings are grouped under seven subdivisions corresponding to six major geographic regions and a general statewide category. Outlines of the regions and locations of the study areas are shown on the accompanying index map of Alaska.

GENERAL

Alaskan Mineral Resource Assessment Program

The Alaskan Mineral Resource Assessment Program (AMRAP), authorized by Congress to begin in 1974, calls for an accurate appraisal of Alaska's mineral endowment within 10 yr. A rapid assessment of this vast and potentially mineral rich region is required both to plan a viable long-range national minerals policy and to assist in decisions on Alaskan land use and development over the next decade. The program is administered by H. C. Berg.



Because mineral appraisals of such remote and little-known regions as Alaska are still largely experimental, the program begins with an interdisciplinary experiment to develop specific guidelines, techniques, and products as a model for a statewide mineral inventory. Called the Prototype Alaskan Mineral Resource Assessment Program (PAMRAP), this 2-yr program of reconnaissance geologic mapping and other field and laboratory studies will also provide greatly improved mineral-resource information for selected prototype study areas. Four 1:250,000-scale (1°×3°) quadrangles totaling 71,225 km^2 are undergoing resource appraisal under PAMRAP. The second (statewide) phase of the program is called AMRAP and is simply the long-range continuation of PAMRAP. AMRAP began on July 1, 1975, and will continue for approximately 10 yr. Nine 1:250,000-scale quadrangles, totaling about 121,729 km^2, tentatively are scheduled for resource appraisal in the next 2 yr under AMRAP.

Alaska geothermal study

As part of a statewide study to assess the geothermal potential of Alaska, T. P. Miller and R. L. Smith completed reconnaissance geologic mapping of the calderas of the Alaska Peninsula between Katmai National Monument and Unimak Island in the eastern Aleutian Islands. The distribution of ash flows surrounding the calderas has been determined, and laboratory studies are continuing on their composition and age. These studies, the first to be done on most of these calderas, should provide general understanding of the volcanic history of these eruptive centers.

Gravity anomalies associated with igneous rock units in southeastern Alaska

D. F. Barnes completed gravity traverses along all the shorelines of southeastern Alaska, and the resulting series of 1:250,000 simple-Bouguer-anomaly maps reveals some important correlations between lithologic units and the gravity field. Earlier reconnaissance and marine gravity surveys had shown that the dominant feature of the gravity field is a regional gradient from positive anomalies along the western coast of the archipelago to a low of about −100 mGal along the Canadian border (Barnes, 1972). The more detailed gravity data show that

this gradient is not constant but flattens out and is locally reversed along a central belt that extends from Lynn Canal through Clarence Strait. The positive anomalies along this belt are generally associated with known mafic outcrops, the largest positive anomalies being associated with the Duke Island Ultramafic Complex (Irvine, 1967) in the south and the gabbro near Haines in the north, each of which causes local gravity highs of 30 to 40 mGal. An outer belt of positive anomalies follows the mafic rocks on the western coast of Baranoff Island, northward through the entrance to Cross Sound and probably to the La Perusse intrusive, where no data have been obtained.

A wide variety of anomalies is associated with the granitic intrusives. Many are gravity lows, but an equally large number are gravity highs, and the differences may reflect the age and environment of the intrusive. For example, a marked gravity low is associated with the Tertiary granitic intrusive near Baranoff Hot Springs, but nearby intrusives of similar age and lithology appear to be gravity highs.

NORTHERN ALASKA

New graptolite discovery indicates Lower Ordovician rocks in southwestern Brooks Range

A thin calcareous mudstone interval within the thick metacarbonates of the Baird Group around Hub Mountain, in the northwestern Baird Mountains quadrangle, yielded a stratified and exceedingly well preserved graptolite fauna (loc. 1, index map). The new locality occurs on the southern edge of the carbonate terrane, about 38 km south of the original graptolite locality (Tailleur and others, 1973). I. L. Tailleur, W. B. Hamilton, and C. F. Mayfield (USGS) and G. H. Pessel (Alaska Division of Geological and Geophysical Surveys) collected two graptolite assemblages from mudstone beds within 5 m north of a steeply dipping marble contact. Claire Carter identified forms indicative of Darriwillian (Middle Ordovician) and Castlemainian (Early Ordovician) Ages in one of the collections and Bendigonian Age (Early Ordovician) in the other.

Most of Early Ordovician and some Middle Ordovician time seems to have been condensed into about 6 m of strata in which graptolites survived regional metamorphism. Mudstone, interbedded black mudstone and carbonate, and light-colored carbonate below the collections comprise enough thickness to extend the sedimentary record into Cambrian time, nearly completing the Phanerozoic record for one of the juxtaposed sequences in the western Brooks Range. The thick Paleozoic carbonate section with a thin interval of Lower and Middle Ordovician basinal deposits nearly duplicates the coeval section in the York Mountains on Seward Peninsula.

Metamorphism in the southwestern Brooks Range

Continuing examination of field and petrologic data from the Ambler River quadrangle and the eastern half of the Baird Mountains quadrangle is being carried out by C. F. Mayfield (USGS) on rocks collected since 1955 by G. H. Pessel and R. E. Garland (Alaska Division of Geological and Geophysical Surveys), by W. P. Brosgé, R. B. Forbes, T. P. Miller, W. W. Patton, Jr., H. N. Reiser, and I. L. Tailleur (USGS), and by a mining company (loc. 2). Preliminary results indicate a belt of sedimentary, volcanic, and plutonic rocks along the southern edge of the Brooks Range (Pessel and others, 1973a) up to 40 km wide that has been regionally metamorphosed to the greenschist facies. Pelitic schists contain quartz, albite, muscovite, chlorite, and varying amounts of chloritoid, calcite, tourmaline, magnetite, and carbon. Metabasites contain albite, chlorite, and sphene and occasionally amphibole, epidote, calcite, pyrite, or magnetite. Granitic orthogneisses contain quartz, potassium feldspar, albite, muscovite, and minor amounts of biotite, zircon, pyrite, or magnetite. Garnet-bearing schist zones occur discontinuously within this belt in the southeastern Ambler River quadrangle and the northeastern and central Baird Mountain quadrangle. Retrograded glaucophane, suggesting an early stage of high-pressure metamorphism, occurs in metabasites and a few pelitic schists (Forbes and others, 1973) within the garnet zone in the southeastern Ambler River quadrangle and is preserved only in metabasites from the garnet zones of the central and northeastern Baird Mountains quadrangle. A gradual decline of metamorphic grade occurs both north and south of the schist belt, pumpellyite-grade metamorphism in scattered mafic rocks trailing off to a terrane of virtually unmetamorphosed basaltic rocks and sediments.

At least two regional metamorphic events are indicated by superimposed and widely divergent planes of schistosity, both in thin section and in outcrop. Potassium argon ages on muscovite for two samples of quartz mica schist, one from the central Baird Mountains quadrangle and the other from nearby in the Selawik quadrangle, are 122±3.7 m.y. and 108.5±3.3 m.y., respectively. It is likely that these ages date the waning stages of greenschist metamorphism in the area. This is in contrast to a 213-

m.y. isochron from K-Ar dates on paragonite, which Turner (1973) accepts as the age of the culminating metamorphic event in the eastern part of the Ambler River quadrangle.

Light-colored orthogneisses scattered throughout the metamorphic belt had a wide variety of compositions ranging from granite and syenite to quartz diorite and diorite. Alkalic metaigneous rocks occur as small stocks, plugs, and dikes exclusively in the Kallarichuk Hills of the central Baird Mountains quadrangle. They exhibit a weak metamorphic texture even though they are often enclosed by highly schistose and garnetiferous country rocks, which indicate their intrusion either at a late stage of the last metamorphic event or after a strong metamorphic even but before a second weaker event.

Significant stratiform sulfide mineralization of high-grade copper, lead, zinc, and silver occurs within the garnet zone from the eastern Ambler River quadrangle. Proven reserves are estimated in excess of $2 billion (C. C. Hawley, unpub. data, 1973) with good prospects for finding additional reserves. Mining companies consider the sulfides to be of volcanogenic origin.

WEST-CENTRAL ALASKA

Regional geologic controls of the gold deposits near Nome

The strong areal localization of the gold placer areas within the regionally metamorphosed terranes of the central Seward Peninsula has been recognized since the earliest geologic fieldwork 75 yr ago. The additional association of placer areas with certain rock types has also been known. However, for want of viable stratigraphy of the country rocks of the region, the gross geologic controls to account for the established empirical relationships could not be determined.

The combined results of both the early workers and the more recent field investigations by C. L. Sainsbury, C. L. Hummel, and others throughout the central Seward Peninsula established the general distribution of several gross suites of country rocks and their northward trend north and south of the eastward-trending Kigluaik and Bendeleben uplifts. But the major regional structures accounting for their distribution and trend were not determined.

All previous work suggested that only in the southwestern portion of the Seward Peninsula (loc. 3) are the exposure, character, and structure of the metamorphic rocks comprising the bedrock adequate to allow them to be subdivided and mapped extensively and, thereafter, to be used to delineate regional structural elements. These tasks have now been largely accomplished by Hummel throughout the 5,000-km^2 portion of the southwest Seward Peninsula that encompasses the most productive placers on the entire peninsula, unmined placers of high potential, and the lodes from which the placers were derived.

Two placer belts, which have yielded the greatest production and still contain the greatest potential of the region, extend northward from Nome and Solomon for approximately 50 km. Both belts are now interpreted to coincide with the axial anticlines that constitute deformed remnants of folds that once extended northward across the entire central Seward Peninsula; however, their central portions were destroyed by and over the younger Kigluaik uplift.

The main localization of the gold-quartz and base-metal veins and the gold placers derived from them were preferentially effected in the rocks making up the cores of the anticlines where they were transected by major northeast-striking strike-slip faults and by a coordinate but subordinate set of northwest-striking lesser faults and fractures.

Southeastern Seward Peninsula

Reconnaissance studies by T. P. Miller of three large granitic plutons in the southeastern Seward Peninsula (loc. 4) showed that the Darby pluton has well above average amounts of uranium and thorium (11.2 ppm and 58.7 ppm, respectively), the Kachauik pluton has average to above average uranium and thorium (5.7 ppm and 22.5 ppm, respectively), and the Bendeleben pluton contains average amounts of uranium and thorium (3.4 ppm and 16.7 ppm, respectively). These three plutons show compositional and textural differences indicative of different source materials and (or) crystallization histories that may have controlled the distribution of uranium and thorium.

New information on the Kaltag fault

Ground and aerial inspections of the Kaltag fault between Tanana and Unalakleet were carried out by W. W. Patton, Jr., R. M. Chapman, George Plafker, and W. E. Yeend (loc. 5). No fresh breaks or other evidences of modern activity along this part of the fault were found. However, offset streams, ponded drainages, and slice and shutter ridges of bedrock and gravel along the fault zone attest to significant movement in Holocene time. Tilted nonmarine coal-bearing deposits of probable late Tertiary age were observed at three localities within the fault zone.

In the Melozitna quadrangle, blueschist facies rocks were discovered in Precambrian(?) and Paleozoic metamorphic assemblages north of the fault. These blue amphibole-bearing rocks appear to represent the offset extension of the blueschist facies terrane in the Kaiyuh Hills (Forbes and others, 1971) and provide additional support for previously published estimates (Patton and Hoare, 1968) of about 140 km of right-lateral offset along this segment of the Kaltag fault since Cretaceous time.

EAST-CENTRAL ALASKA

The Mount Doonerak structural high

The southernmost Carboniferous rocks in the central Brooks Range are in the northern Wiseman quadrangle (loc. 6). Two distinct sequences, one on the northern flank of the Doonerak structural high and the other in the Savioyok synclinorium, provide distinct contrasts in depositional and structural styles.

North of Doonerak, a relatively thin, autochthonous sequence of clastic limestones and limy mudstones (Lisburne Group) overlies the thin Kayak Shale, which, in turn, unconformably rests on lower Paleozoic volcanic rocks that make up the structural high. This sequence is similar to the one recently mapped in the northeastern Brooks Range where the Lisburne underlain by a thin Mississippian clastic unit unconformably overlies strongly folded and faulted lower Paleozoic rocks.

In contrast, the thicker Lisburne sequence in the Savioyok synclinorium displays rapid facies changes in a relatively short north-south distance. Light-colored shelf dolomites dominate on the southern flank of the basin, while deeper water dark limestones and shales predominate on the north. In this structure, the Lisburne and Kayak are underlain by a thick sequence of Upper Devonian clastic rocks, the more normal pattern for most of the central Brooks Range.

Detailed fieldwork by H. N. Reiser and J. T. Dutro, Jr., indicated that large-scale displacements are not necessary to explain the occurrence of these contrasting sequences in such close geographic relation. Detailed lithologic and biostratigraphic study of the Lisburne of these sequences by A. K. Armstrong is continuing.

Mated metamorphic beds in southern Brooks Range

Previous work has shown that garnet and amphibole rocks, including both blueschist and amphibolite, occur in a zone about 10 km wide within the pelitic schists that form the southern edge of the Brooks Range in the southeastern part of the Ambler River quadrangle (Forbes and others, 1971; Pessel and others, 1973b). Petrographic data have recently been compiled by W. P. Brosgé, H. N. Reiser, I. L. Tailleur, R. B. Forbes, and C. F. Mayfield (USGS) and by G. H. Pessel (Alaska Division of Geology and Geophysical Surveys) for the adjacent Survey Pass, Wiseman, and Chandalar quadrangles (loc. 7) to be used in preparing a small-scale metamorphic facies map of Alaska. These data show that within the schists of lower greenschist facies that characterize most of the southern Brooks Range, a zone of garnet-bearing schist 5 to 15 km wide extends eastward almost continuously for about 340 km from the southeastern Ambler River quadrangle to the northeastern part of the Chandalar quadrangle. In the western 150 km of this zone, chloritoid and biotite are also common, and glaucophane was found every 15 or 30 km in samples from metasedimentary as well as mafic rocks. Kyanite occurs east of the last known glaucophane locality, in samples from the eastern Survey Pass and western Wiseman quadrangles. In most of the Wiseman and Chandalar quadrangles, glaucophane and kyanite are absent in the garnet zone, chloritoid is rare, and biotite is common, but at the eastern end of the zone, glaucophane occurs again as almost completely chloritized relics in retrograded amphibole schist. Elsewhere in the zone, the glaucophane is fresh to partly chloritized.

Granitic plutons crop out a few kilometres north of the zone in the Survey Pass quadrangle where the partially altered glaucophane and garnet and local biotite in the western half of the zone indicate a thermal overprint on an earlier high-pressure assemblage previously described in the southeastern Ambler River quadrangle (Alaska Division of Geology and Geophysical Surveys, 1973, p. 34–36). Granitic plutons lie within the zone in the Chandalar quadrangle, and the garnet-biotite assemblage in the Wiseman and Chandalar quadrangles indicates that most of the eastern half of the zone is the product of low-pressure thermal metamorphism. However, the rare occurrence of almost completely altered glaucophane and garnet near the granite at the eastern end of the zone suggests that the high-pressure assemblage may originally have extended throughout the zone. In any case, it seems that a long, narrow zone of thermal metamorphism was either coextensive with or in linear continuity with a long, narrow zone of high-pressure metamorphism.

Age revision suggested for chert unit in the Kuskokwim Mountains

A widespread unit of chert, with some interbedded gray slate and slaty shale, that forms the northern end of the Kuskokwim Mountains in the Kantishna River quadrangle (loc. 8) was examined during reconnaissance geologic mapping by R. M. Chapman. W. W. Patton Jr. and W. E. Yeend. This unit, which was originally outlined by H. M. Eakin (1918) and designated as probably early Mesozoic in age, forms a belt 16 to 26 km wide and about 72 km long that extends southwest from the upper Zitziana River to near Lake Minchumina.

The chert is predominantly medium to medium-dark gray and, in minor part, varicolored and forms prominent hills that generally range in altitude from 487 to 792 m. The chert outcrops and rubble weather to various shades of light yellow, tan, and orange and give the semibarren ridges a distinctive appearance. The beds generally strike northeast and dip steeply south to near vertical. No reliable estimate of thickness can be made on the basis of present information, but probably the unit is at least 600 to 700 m in thickness. Complex folding is apparent, and, in part, the section may be overturned; therefore, the unit is probably not as thick as might be inferred from the width of the outcrop belt.

Provisionally, this chert unit is believed to be correlative with a similar chert unit in the Dugan Hills, about 80 km northeast and just north of the Tanana River. The chert unit in the Dugan Hills has been identified by Péwé, Wahrhaftig, and Weber (1966) as the upper part of the Nilkoka Group of Precambrian or early Paleozoic age. An early Paleozoic, possibly Ordovician, age for both of these chert units is most probable, based on recent regional interpretations. The probably early Mesozoic age inferred by Eakin (1918) for the chert unit in the Kantishna River quadrangle no longer seems tenable.

Vertebrate fossil discovery

A vertebrate fossil site discovered by F. R. Weber on Canyon Creek in the Big Delta quadrangle (loc. 9) was examined by Weber, D. M. Hopkins, and T. D. Hamilton. Bones of a small horse, *Camelops*, bison, mammoth, *Saiga*, wolf, rabbit, and caribou (?) from the same stream channel fill have been identified by C. A. Repenning. Although remains of these animals are common in Alaskan Pleistocene deposits, they are seldom found in stratigraphic context, and this find, probably the first authentic association of *Camelops*, an extinct North American camel, with *Saiga*, an extant Asiatic antelope, suggests the mixing of major faunal types across the Bering Straits land bridge, probably in late Pleistocene time.

Mineral potential in the Big Delta B-1 quadrangle

Reconnaissance geologic mapping in the Big Delta A-1 and B-1 quadrangles (loc. 10) by H. L. Foster, F. R. Weber, and T. E. C. Keith indicated that granitic plutons of the same type that appear to be related to copper-molybdenum mineralization in the neighboring Eagle and Tanacross quadrangles extend into the Big Delta quadrangle, especially in the vicinity of Tibbs Creek. Other metallic minerals in the B-1 quadrangle include previously mined gold and antimony and molybdenum.

Metamorphosed peridotite in southeastern Big Delta quadrangle

Several small metamorphosed peridotite bodies were found by H. L. Foster, T. E. C. Keith, and F. R. Weber in the Big Delta quadrangle (loc. 11) during reconnaissance geologic mapping. The ultramafic rock is foliated and folded and has been subjected to the same regional metamorphism as the surrounding country rock. The ultramafic rocks appear to have a different history than those recently described in the Eagle quadrangle, with the exception of one body in the Eagle A-6 quadrangle south of Mount Harper.

The several separate small bodies originally may have been part of one or more larger bodies that were tectonically broken up and separated.

Mankomen Group (Pennsylvanian and Permian) revised

The Mankomen Formation was raised to group rank in its type area, the Eagle Creek valley, by D. H. Richter and J. T. Dutro, Jr. (loc. 12). Two new formations are recognized. The Mankomen is underlain conformably by the Tetelna Volcanics, consisting of massive volcanic flows and volcaniclastic rocks of Pennsylvanian age. The Nikolai Greenstone of Middle and (or) Late Triassic age rests unconformably on the Mankomen.

Fusulinids in the lowermost volcaniclastic part of the Mankomen are Pennsylvanian (Atokan) in age. Fossils higher in the group range from Wolfcampian to Leonardian and, possibly, Guadalupian age.

The Tetelna Volcanics reflect the development of a late Paleozoic volcanic arc whose waning stages are represented by the volcaniclastic rocks of the lower Mankomen. Lithologies of the Tetelna-Mankomen strata and the new age data suggest that this

arc had become virtually inactive by Early Permian time (Richter and Dutro, 1975).

SOUTHERN ALASKA

Depositional environments of coal-bearing group

According to I. F. Ellersieck and Clyde Wahrhaftig, the Healy Creek Formation and Suntrana Formation below the number one bed are characterized by crosscutting lenses of sand and conglomerate that are not continuous along strike for more than a few metres (loc. 13). The Suntrana Formation above the number one bed and the Lignite Creek Formation have repetitive fining-upward sequences of sedimentation. Individual cycles in these formations consist of, from base to top, conglomerate, coarse pebbly sandstone with lag accumulations of pebbles, crossbedded sandstones, silty clay, and coal. These idealized sequences are often truncated by an erosional surface above which a new cycle begins. Complete cycles range from 5 to 30 m thick.

Ultramafic rocks in the eastern Alaska Range

Regional mapping and petrologic studies by W. N. Sharp and D. H. Richter indicated that the alpine ultramafic rocks in the low greenschist facies metamorphic terrane north of the Denali fault in the eastern Alaska Range (loc. 14) are confined to two parallel, but possibly genetically distinct, narrow belts. The belts, approximately 25 km apart, trend N. 70°–75° W. and are transected on the west by the Denali fault.

Ultramafic rocks along the 175-km-long northern belt consist principally of intimately mixed serpentinite and clinopyroxene-dominant serpentinized pyroxenite, peridotite (wehrlite), and dunite. Rodingite inclusions, sometimes with nephrite rims, and chromite segregations are locally common. The host rock for the entire northern belt is a phyllite-marble sequence that has been locally converted to chrome-spinel-bearing assemblages of magnesite, dolomite, and wollastonite at the ultramafic contact. Ultramafic rocks in the shorter southern belt are more homogeneous than those in the northern belt and consist principally of orthopyroxene-dominant serpentinized peridotite (lherzolite) associated with gabbro, hornblende gabbro, and anorthosite. Both the mafic and ultramafic rocks occur within a sequence of metavolcanic and metavolcaniclastic rocks; no evidence of thermal metamorphism is apparent.

These briefly described features suggest that the ultramafic rocks in the northern belt were injected as a hot crystal mush along a major crustal fracture, whereas those in the southern belt were emplaced mechanically, and while relatively cold, into a subducted volcanoplutonic arc.

Granitic plutonism and metamorphism in the eastern Alaska Range

Evaluation of K-Ar mineral ages by D. H. Richter, M. A. Lanphere, and N. A. Matson, Jr., indicated that plutonic rocks in the eastern Alaska Range (loc. 15) were emplaced in Late Pennsylvanian time (282 to 285 m.y.) and during two distinct intervals in Cretaceous time (105 to 117 m.y. and 89 to 94 m.y.). Development of a large plutonic-metamorphic complex, consisting of diorite and quartz diorite intimately associated with banded gneiss and other metamorphic rocks, apparently occurred during Late Triassic to Middle Jurassic time (163 to 199 m.y.). A smaller plutonic-metamorphic complex is Miocene in age (17 m.y.).

The younger Cretaceous plutons are recognized only in the regionally metamorphosed Devonian and older terrane north of the Denali fault. Plutons of the older Cretaceous and Pennsylvanian events are restricted to Pennsylvanian and younger terrane south of the Denali fault and are associated with coeval volcanic rock assemblages. The major plutonic-metamorphic complex is also restricted to the terrane south of the Denali fault and may relate to collapse of a late Paleozoic volcanic arc in Triassic time, followed by syntectonic magmatism in the Jurassic. The Miocene plutonic-metamorphic complex may reflect the time of initial movement along the Denali fault.

Genesis of Kennecott-type copper deposits

Detailed stratigraphic and petrographic studies by A. K. Armstrong and E. M. MacKevett, Jr., of carbonate rocks that host Kennecott-type copper deposits, augmented by previous geologic studies, indicated that sabkha processes were involved in the ore gensis. The Kennecott deposits are localized in the largely dolomitic lowermost 100 m of the Chitistone Limestone (Upper Triassic) (loc. 16). The lowermost 100 m of the Chitistone formed in cyclic subtidal to supratidal environments and contains abundant stromatolites, mud chips, and pseudomorphs of sulfate-bearing evaporites. This sequence disconformably underlies marine limestone.

The copper in the Kennecott-type deposits was probably derived from the Nikolai Greenstone, a thick, widespread subaerial succession of basalt subjacent to the Chitistone that has an intrinsically

high copper content. A hydrologic regimen during which highly oxygenated water dissolved substantial amounts of copper from the Nikolai and subsequently deposited the copper in the reducing environment of the sabkha is postulated. The present configurations of the deposits may reflect some remobilization and displacement during Jurassic or Cenozoic tectonic and plutonic events.

Relations between Alexander and Taku-Skolai terranes in the McCarthy quadrangle

Field investigations in the McCarthy quadrangle (loc. 17) by E. M. MacKevett, Jr., and D. L. Jones provided additional data in support of the contention that the Taku-Skolai and Alexander terranes, two of the major subjacent structural units of southeastern Alaska, eastern south-central Alaska, and nearby parts of Canada (Berg and others, 1973), are juxtaposed by faulting.

The westernmost known extent of the Alexander terrane—in the eastern part of the McCarthy quadrangle—is represented by the mid-Paleozoic Kaskawulsh Group (Canadian usage), which contains locally fossiliferous marble and some schist and amphibolite. These rocks are flanked on the north, west, and south by locally metamorphosed upper Paleozoic sedimentary and volcanic rocks and associated intrusive rocks of the Taku-Skolai terrane. Although most boundaries of the two terranes are concealed by snow, ice, and Wrangell Lava (Cenozoic), the southern and southwestern contacts, in places, are well exposed. These contacts are faults that dip 50° to 60° southwest to west and separate Alexander terrane marbles from a gabbro complex or metamorphic rocks of the Skolai Group (Permian). The gabbro complex underlies the Skolai Group and is interpreted as a basal part of the Taku-Skolai terrane. The complex is cut by abundant monzonite plutons of late Paleozoic age. Contacts marking the northern boundary of the Alexander terrane are concealed or partly obscured, but they also appear to be faults.

The mechanics of the faulting and the amount of movement that occurred are conjectural. The configuration of the bounding fault (or faults), characterized by a large diversity in strikes, suggests that the Taku-Skolai terrane was thrust over the Alexander terrane along a major regional megathrust with many tens of kilometres of displacement. The fact that no klippen of Taku-Skolai rocks have been found on the Alexander terrane may be attributable to the extreme Cenozoic uplift and attendant vigorous erosion of the region and to the limited, broad reconnaissance nature of field investigations, both in Alaska and in Canada.

Petrography, age, and tentative correlation of the schist at Willow Creek, southwestern Talkeetna Mountains

Detailed geologic investigations by Béla Csejtey, Jr., and K-Ar age determinations by J. G. Smith on the enigmatic schist at Willow Creek suggested that the schist had a complex and still not fully known geologic history (loc. 18).

The schist crops out in an approximately 16× 6-km block in the southwestern Talkeetna Mountains. The block was intruded on the north by Upper Cretaceous and lower Tertiary plutons, and it is bounded on the south by the Cenozoic Castle Mountain fault. Rocks lithologically similar to the schist at Willow Creek have not been found in nearby regions.

Lithologically, the schist at Willow Creek is a highly schistose, medium-grained rock with uniform lithology throughout its exposure area. Its ubiquitous constituents are quartz, muscovite, albite, chlorite, numerous chloritized grains of garnet and subordinate biotite, and sparse stringers of carbonaceous material. Small, open folds and crenulations are common througout the schist block. The axial planes of these crenulations form an incipient slip cleavage at a large angle to the primary schistosity.

The present mineral assemblage of the schist is that of the greenschist metamorphic facies. However, it is retrograde from higher metamorphism, possibly the amphibolite facies, as evidenced by the chloritized garnet and biotite crystals and sparse mineral outlines consisting now of chlorite, which are probably pseudomorphs after hornblende. The time relation between this retrograde metamorphism and the incipient slip cleavage is unknown, as is the time gap between these later events and the primary metamorphism.

Potassium-argon age determination on muscovites from three separate localities yielded early Tertiary ages, around 60 m.y. Although it is not known which metamorphic event or what thermal effect these dates identify, they tend to disprove, in conjunction with regional geologic considerations, the previously assigned Precambrian or early Paleozoic metamorphic age for the schist.

The uniform petrography of the schist at Willow Creek, the presence of serpentinized ultramafic bodies, and the lack of similar rocks in adjacent regions suggest that the schist block is a tectonically emplaced fragment of a larger metamorphic terrane.

Ongoing petrologic research and additional K-Ar age determinations will hopefully decipher the complex geologic history of the schist at Willow Creek.

Rocks within the schist block are similar in lithology and K-Ar ages to metamorphosed Upper Paleozoic rocks, about 200 km to the east, in the Chugach Mountains north of the Border Ranges fault (H. C. Berg, unpub. data, 1974). These rocks are interpreted by MacKevett and Plafker (1974) to be part of the upper plate of a late Mesozoic and early Tertiary subduction system.

SOUTHWESTERN ALASKA

Tectonic significance of Lower Cretaceous rocks in the Bristol Bay area

Recent studies by J. M. Hoare, W. L. Coonrad, R. L. Detterman, and D. L. Jones yielded interesting new data on the age and structure of the Mesozoic rocks north of Bristol Bay (loc. 19). Strata of Early Cretaceous age, which are exposed in the Goodnews A-3 quadrangle and parts of the adjoining A-2 and B-2 quadrangles, are particularly interesting because (1) they are 2,500 to 3,500 m thick and are the least deformed thick section of Lower Cretaceous rocks known in southwestern Alaska; (2) they are richly fossiliferous; (3) they include a coeval limestone facies and a conglomeratic facies; (4) they contain clear evidence of Late Jurassic tectonic activity; and (5) they are restricted to a small area and were preserved by tectonic activity.

These Lower Cretaceous strata unconformably overlie Lower Jurassic volcanic rocks in an area of about 450 km^2 between the Ungalikthluk and Kulukak Rivers. They were apparently preserved from erosion in a structurally low tectonic block largely defined by the Ungalikthluk and Kulukak faults. The Valanginian strata were deposited as two contrasting lithologic facies, both of which contain coquinas of *Euchia crossicolis*. One facies consists of 180 m of limy grit and fine conglomerate with interbedded *Buchia*-shell limestone. The other consists of about 1,000 to 1,500 m of conglomerate with interbedded siltstones and *Buchia* coquinas. The unlike clasts indicate that the two facies had different source terranes. The two facies must have been deposited some distance apart, but they now crop out in two parallel belts that are only 2 to 5 km apart. The belts are on either side of a reverse fault that dips southeastward. The facies have apparently been telescoped by southeastern compression.

The highly calcareous strata of Valanginian age contain abundant phyllite and fine-grained schist clasts. The source of these clasts is the Lower Jurassic volcanic rocks, which are locally metamorphosed in the vicinity of faults. The Lower Jurassic volcanic rocks were apparently metamorphosed by tectonic activity in Late Jurassic time because no rocks of Late Jurassic age are known and no metamorphic clasts were found in a thick marine section of Middle Jurassic age.

The restricted occurrence of the Lower Cretaceous rocks can probably be explained in one of two ways. The simple explanation is that they were preserved from erosion in a structurally low tectonic block between reverse faults that dip steeply southeast. A more radical explanation is that they were preserved beneath a large allochthonous plate of Jurassic volcanic rocks and are now exposed in an erosion window.

Precambrian rocks in southwestern Alaska

The Kanektok basement complex is a narrow, discontinuous belt of schists and gneisses in southwestern Alaska (loc. 20). It is named for the Kanektok River, which flows westward across the complex. The belt, about 130 km long, extends northeastward from near Jacksmith Bay on the Bering Sea coast along the northwestern flanks of the Ahklun and Kilbuck Mountains. The complex was originally defined by J. M. Hoare and W. L. Coonrad (1959, 1961) during the reconnaissance mapping of the Bethel and Goodnews 1:250,000-scale quadrangles. A Precambrian age was assigned to the crystalline rocks in the complex because they are strongly metamorphosed, whereas nearby fossiliferous strata of Devonian and Permian age, although severely deformed, are not significantly metamorphosed.

Confirmation of the occurrence of Precambrian rocks in Alaska has recently become a matter of considerable interest, particularly in relation to plate tectonic modeling of Alaska. R. B. Forbes, in a petrographic study of the specimens collected during the original investigation, identified sedimentary and volcanic rocks as well as some mafic and granitic intrusive rocks metamorphosed in the upper greenschist and lower almandine-amphibolite facies. Potassium-argon dating of mineral separates from three different specimens by D. L. Turner (Geophysical Institute, Univ. of Alaska) yielded hornblende ages of $1{,}072 \pm 32$ m.y. and 533 ± 16 m.y. and a biotite age of 437 ± 13 m.y. These initial data suggest that the rocks are indeed of Precambrian age and that they were subjected to thermal overprinting in Ordovician time or later.

The Kanektok complex is apparently the first Alaskan terrane to yield K-Ar dates suggesting a

Precambrian age. Additional work is being undertaken to obtain more isotopic age measurements and to delineate the age relationship within the Kanektok complex.

SOUTHEASTERN ALASKA

Tertiary granitic rocks dominate Coast Range batholithic complex in northern southeastern Alaska

New studies along the international boundary in the Tracy Arm-Fords Terror Wilderness Study Area by D. A. Brew, A. B. Ford, and D. A. Grybeck, continuing studies by Brew and Ford in the Juneau Icefield area, and available reconnaissance information on intervening and adjacent areas indicated that granodiorite and quartz monzonite of established or inferred middle Tertiary age probably underlie most of the Coast Range batholithic complex between the Stikine River and the Skagway area (loc. 21). Several bodies are represented, the largest of which appears to be the 50-m.y.-old "Turner Lake" body of the Juneau Icefield area. In general, the bodies intrude granitic gneisses to the southwest, but, locally, they extend across the granitic gneiss belt almost to the schist belt that forms the southwestern boundary of the Coast Range batholithic complex. To the northeast, the bodies intrude thermally metamorphosed rocks that are largely of Mesozoic age. At a very few places the Tertiary granitic bodies are associated with volcanic rocks that may be comagmatic.

Timing of metamorphism and plutonism in the Coast Mountains near Ketchikan

New K-Ar determinations by J. G. Smith from southern southeastern Alaska (loc. 22) delineated three belts, each with a distinctive pattern of ages that coincides with major rock units in the Coast Range metamorphic-plutonic complex. More than 70 K-Ar determinations, including 30 biotite-hornblende pairs, were made on metamorphic and plutonic rocks collected across the Coast Range from Stewart, British Columbia, to near Ketchikan, Alaska. From east to west, the ages most probably represent (1) intrusive ages of Eocene plutons, (2) a middle Tertiary thermal-metamorphic event, and (3) partial to complete resetting of older ages, probably by the middle Tertiary thermal event.

The eastern belt consists, with but one exception, of concordant 50-m.y. biotite-hornblende ages from unfoliated leucocratic quartz monzonite and granodiorite plutons (for example, Hyder Quartz Monzonite, Boundary Granodiorite). The single exception is the Texas Creek Granodiorite, a small pluton that gives strongly discordant ages of 200 m.y. on hornblende and 120 m.y. on biotite. This pluton is intruded by the Hyder Quartz Monzonite. The preservation of older ages in a terrane of younger plutons and the closely concordant 50-m.y. biotite and hornblende ages suggest that the 50-m.y. ages are intrusive ages and not a reflection of the regional cooling history.

Ages in the central belt are mildly discordant: hornblende averages about 50 m.y., and biotite about 44 m.y. Rocks in this belt are sillimanite- and kyanite-grade schists, gneisses, and migmatites and foliated diorite, quartz diorite, and granodiorite. Mineral ages show no correlation with rock type or position in the belt. Instead, biotite ages are about the same throughout the belt, as are hornblende ages, although there is a 6-m.y. difference between the two groups. This pattern of apparent ages in a high-grade metamorphic terrane suggests that the ages were set by a middle Tertiary thermal-metamorphic event.

The western belt consists of apparent ages that increase from 52 m.y. (hornblende) and 44 m.y. (biotite) in the east to 80 to 85 m.y. along the western shore of Revillagigedo Island. Rocks in this belt are metasedimentary and metavolcanic schists and gneisses of greenschist to lower amphibolite facies and foliated quartz diorite and subordinate granodiorite. Biotite and hornblende ages increase from east to west, but at different rates. Discordance is about 8 m.y. in the east, increases to 20 m.y. near the middle of the belt, and decreases to a few million years in the west. This pattern suggests that rocks yielding apparent ages of 80 to 85 m.y. were reset by a heat source to the east.

PUERTO RICO

Age relations in the San Lorenzo batholith

The San Lorenzo batholith occupies an area of approximately 500 km^2 in southeastern Puerto Rico. Recent geologic mapping in the area by C. L. Rogers and new radiometric age determinations by R. F. Marvin furnished a clearer picture of the nature and sequence of intrusion of the batholith. At least three intrusive phases are present.

The oldest rocks in the batholith range in composition from diorite to gabbro, have a radiometric age of about 78.1 ± 2.2 m.y., and occur in small plutons clustered around the margin of the batholith. The major part of the batholith, perhaps 75 percent of the surface area, is granodiorite to quartz in composition and has an average age of about 73.5 ± 2.3 m.y. The youngest unit forms a number of scattered small to moderately large plutons that

range in composition from quartz monzonite and granodiorite near the center of the batholith to quartz diorite near the margin. Age data are not yet available, but almost certainly, this unit was intruded during latest Cretaceous to early Tertiary time.

Back-arc-basin sedimentary rocks and the protrusion of bastite serpentinite

Analysis of faunal and physical characteristics of the Yauco Mudstone, Lago Garzas Formation, and Sabana Grande Andesite of Mattson (1960) in the Ponce Peñuelas, and Yauco quadrangles of southwestern Puerto Rico suggested to R. D. Krushensky that these units were deposited in shallow, warm water in near-shore shelf or lagoonal environments. Features indicative of high-energy shoals or banks and forms indicative of lagoonal environments are both separate and mixed. When they are mixed, coarseness and extreme angularity of the constituent clasts suggest only very short transport before final deposition. Small-ripple bedding and flaser bedding, both abundant in the Yauco, are also characteristic of shallow deposition. Flaser bedding suggests, in addition, alternation in supply of silt and clay, perhaps indicating changes in sediment supply in the wet and dry seasons. Southwestward direction of transport in soft-sediment deformation, crossbedding, and coarsening in the Yauco, as well as northward thickening of the Lago Garzas and the Sabana Grande, suggest that the paleoslope dipped to the south-southwest. Polarity of the arc-trench association suggests that these rocks were deposited in a back-arc basin.

Alpine-type bastite sepentinite was emplaced within and beneath these units, perhaps as protrusive diapirs. Although all previously known contacts are sheared and have been considered faults, one newly exposed contact of serpentinite with the Yauco Mudstone appears unequivocally intrusive, but contact metamorphic effects, even the recrystallization of the calcareous cement of the Yauco, are not apparent. Presumably, these serpentinite bodies are derived from the uppermost mantle or from oceanic crust undergoing subduction. Their rise may have been triggered by a decrease in strength attendant on dehydration that could accompany movement into areas of higher temperature, by a decrease in density accompanying shearing (Lockwood, 1972), by tectonic movement, or by a combination of these factors and perhaps others. The bastite serpentinite of southwestern Puerto Rico appears to correspond to the thermal diapir envisaged by Karig (1971) as intruding the back-arc basins of the western Pacific.

Stratigraphic relations of Cretaceous rocks

Detailed field studies by R. P. Volckmann of Upper Cretaceous rocks in the San German and Puerto Real quadrangles indicated that revision of earlier stratigraphic concepts is necessary. The stratigraphic units involved include the Mayaguez Group and the San German Formation (Mattson, 1960). As originally described (Mattson, 1960), the Mayaguez Group comprised seven lithofacies: the Parguera, Brujo, and Melones Limestones, the Yauco Mudstone, the Sabana Grande Andesite, and the El Rayo Volcanics and Maricao Basalt. The Maricao Basalt crops out north of the area under study and is not included in this discussion. Mattson (1960) believed that each of these seven lithofacies interfingers locally with all of the others and that the Melones Limestone is the youngest of the group. The entire sequence was believed to range in age from Santonian(?) to early Maestrichtian. The San German Formation (Mattson, 1960), thought to be middle Maestrichtian in age and to rest uncomformably on the Brujo Limestone of the Mayaguez Group, consisted of two units: a basal series of andesite flows and agglomerates and a thick, massive limestone, the Cotui Limestone Member, near the top of the formation.

Recent field mapping shows that the San German Formation consists of three units: (1) a basal series of hornblende-rich lavas and breccias, (2) the Cotui Limestone Member, and (3) an upper series of pyroxene-rich tuffs, mudstones, and thin lenses of massive limestone. The Cotui is found to be equivalent to the Brujo Limestone, and, therefore, the San German Formation is not unconformable on the Brujo. The Cotui has been paleontologically dated as late Campanian or older. The upper unit of the San German Formation bears fossils that indicate a Campanian to Maestrichtian age and is lithologically similar to sequences in the Sabana Grande Andesite of the Mayaguez Group. Thus, it is probable that the San German Formation does not overlie the Mayaguez Group. In fact, the lower San German may be older than the Mayaguez Group, whereas the middle and upper parts of the San German are equivalent to the Mayaguez Group.

The Melones Limestone, originally thought to be of early Maestrichtian age (Mattson, 1960), was considered to be at the top of the Mayaguez Group, overlying the El Rayo Volcanics and stratigraphically lower than the San German Formation. How-

ever, recent mapping has shown that the Melones consists of several lenses interbedded with the El Rayo. N. F. Sohl dated the Melones paleontologically as middle Maestrichtian. These data suggest that the El Rayo, with the interbedded Melones Limestone, overlies the rest of the Mayaguez Group in the San German area.

GEOLOGIC MAPS

Much of the work of the USGS 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 USGS; a long-range goal is the completion of geologic maps of the country at scales that will fulfill foreseeable needs and uses.

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

LARGE-SCALE GEOLOGIC MAPS

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

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

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

Many geologic maps are prepared in the search for a better understanding of the processes and mechanisms that affect the Earth's crust. Uses of these maps are growing in number and importance in the field of planning for more logical land use and for such large-scale engineering works as damsites, highway alinements, and subway routes. Actual construction is aided by locating 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 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 USGS geologic investigations program. The 1:250,000-scale 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 constitute more than one-fifth of the geologic mapping program of the USGS. Many State geological surveys also have 1: 250,000-scale geologic mapping programs underway or completed. These efforts by Federal and State surveys as a nationwide program promise to provide geologic map coverage of two-thirds of the United States by 1985; at present, nearly 40 percent is covered. Figures 2 and 3 show the areas of the United States for which 1:250,000-scale maps have been published.

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

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 prov-

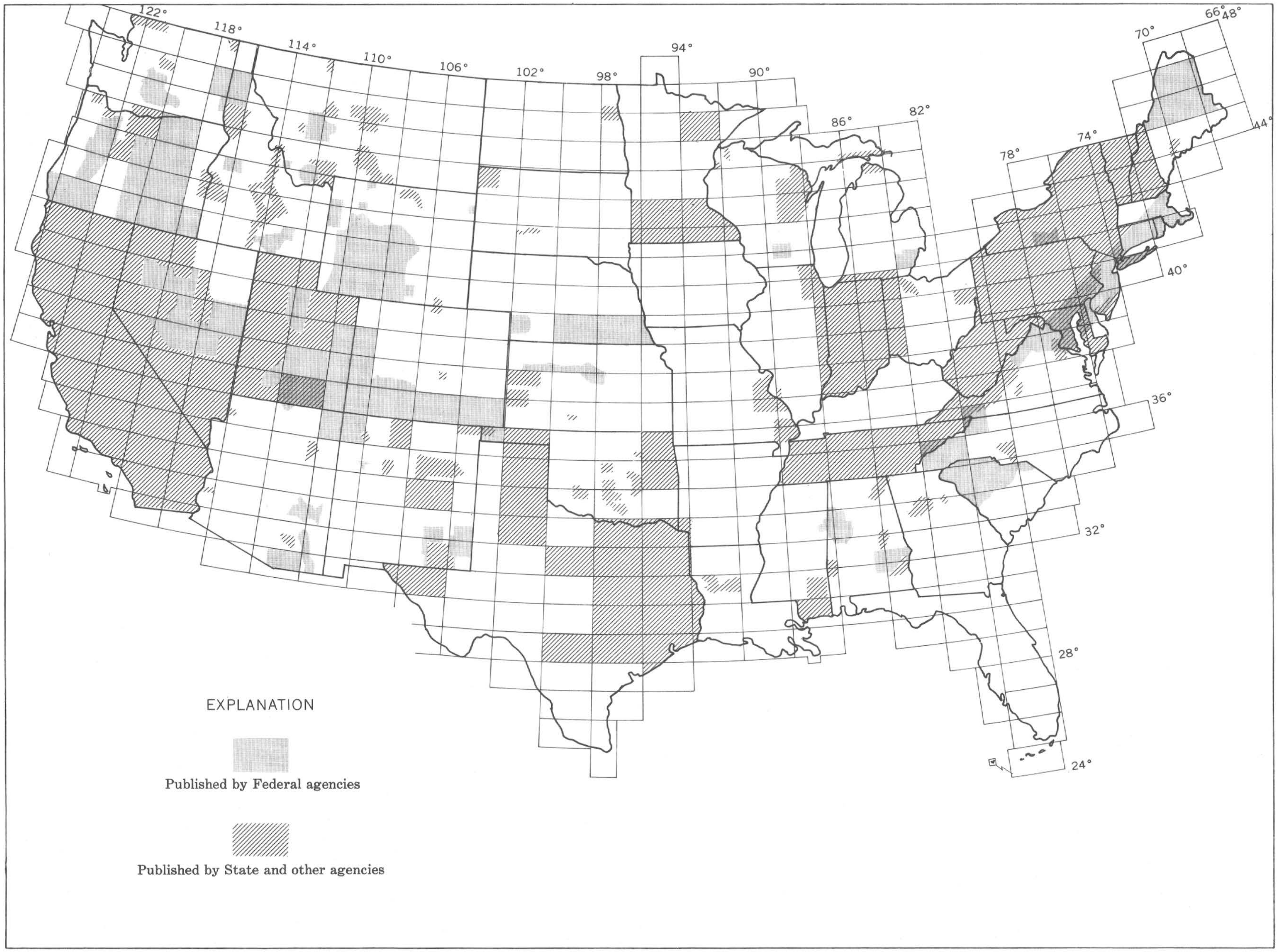


FIGURE 2.—Index map of the conterminous United States showing 1:250,000-scale geologic maps published as of December 31, 1974.

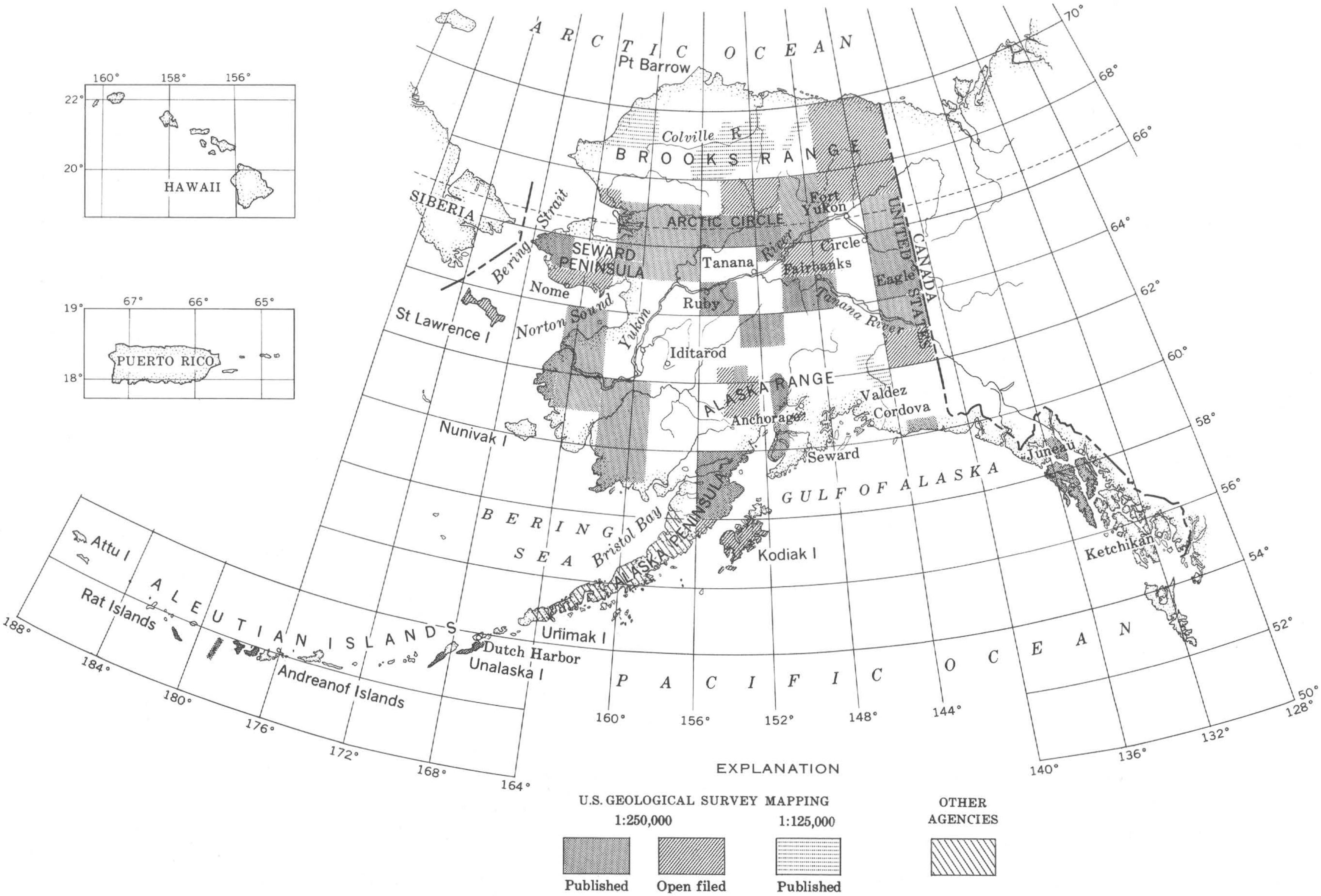


FIGURE 3.—Index map of Alaska, Hawaii, and Puerto Rico showing geologic maps published or on open file as of December 31, 1974.

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

MAPS OF LARGE REGIONS

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

Geologic map of the United States, exclusive of Alaska and Hawaii, scale 1:2,500,000, P. B. King and H. M. Beikman, compilers; three sheets.

Compilation of the new geologic map of the conterminous United States was completed in 1972, and the map was published late in 1974 (King and Beikman, 1974a). The map legend, which comprises the third sheet, shows more than 150 map units arranged horizontally according to age and divided vertically into six general classes of rocks, including marine stratified deposits, continental deposits, eugeosynclinal deposits, volcanic rocks, plutonic and intrusive rocks, and metamorphic rocks. Correlation of Precambrian rocks and of the Phanerozoic plutonic and volcanic rocks is based on radiometric dating. An "Explanatory text to accompany the geologic map of the United States" was published separately (King and Beikman, 1974b).

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

This map is a contribution to the Metallogenic Map of the World, sponsored by the Commission for the Geological Map of the World of the IGC and the IUGS. The map is being prepared in cooperation with the Geological Survey of Canada; the Institute of Geology, National Autonomous University of Mexico; the Geological Survey of Greenland; and the Central American Institute of Investigation and Industrial Technology. The map will show major known deposits of metal-bearing and nonmetallic minerals, as well as their geologic-tectonic settings. A coproduct of the map compilation will be computer storage of data on deposits to facilitate rapid retrieval.

Geologic map of Arkansas, scale 1:500,000, revision by the Arkansas Geological Commission, N. F. Williams, Director, and the USGS, B. R. Haley; assisted by E. E. Glick (USGS) and W. V. Bush, B. F. Clardy, C. G. Stone, M. B. Woodward, and D. L. Zachry (Arkansas Geological Commission).

This revision of the State geologic map, begun in 1968 as a cooperative project, has been completed and is being prepared for publication. The map has been revised on the basis of published and unpublished reports and reconnaissance mapping.

Geologic map of Colorado, scale 1:500,000, O. L. Tweto, compiler.

This new map, begun in 1971, will supersede the existing map published in 1935. The map, which is about 40 percent completed, will depict the vast increase in knowledge of the geology of Colorado during the last 40 yr.

Geologic map of Nevada, scale 1:500,000, J. H. Stewart and J. E. Carlson, compilers.

Compilation of the first comprehensive geologic map of Nevada, prepared in cooperation with the Nevada Bureau of Mines and Geology, has been completed, and the map is being prepared for publication. A preliminary black and white map has been published (Stewart and Carlson, 1974a), and color copy is also available (Stewart and Carlson 1974b). The compilation draws on data from about 500 large- and small-scale maps, many of which have been used previously in compilation of 1:250,000-scale county maps. Field checking and remapping have been done in areas where county maps are incomplete or out of date. The new map will show nearly 100 geologic units.

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

Compilation of this map, which includes more than 50 geologic units, has been completed, and it is being prepared for publication. A map of the western part of the State was published previously (Wells and Peck, 1961), and a preliminary black and white version of the eastern part of the State was published in 1973 (Walker, 1973). The data are based partly on available published and unpublished maps and partly on extensive new reconnaissance and photogeologic mapping. An insert tectonic map shows distribution of fold axes, major surface faults, and

the position of postulated calderas and deeply buried faults.

Geologic map of Wyoming, scale 1:500,000, J. D. Love, compiler.

A new map is being compiled in cooperation with the Geological Survey of Wyoming. This map, which will replace the State map published 20 yr ago, is based 75 percent on new data. Compilation is more than half completed, and parts of the compilation have already been used in a LANDSTAT environmental study, in the RALI program, and in Wyoming Geological Survey county resource reports.

Metamorphic facies map of Alaska, scale 1:2,500,000, D. A. Brew, Chairman, Branch of Alaskan Geology Compilation Committee.

This map is a contribution to the Map of the Metamorphic Belts of the World, sponsored by the Commission for the Geological Map of the World of the IGC and the IUGS, and to the joint USGS-State of Alaska Geological Survey publication on the geology of Alaska. The map will show metamorphic facies, facies groups, facies series, selected isograds, and granitic rock bodies in the style of the IUGS (Zwart and others, 1967) suggested metamorphic facies map explanation. Progress includes preliminary compilation and review of regional metamorphic facies maps at 1:1,000,000 scale for all of the State and coding of background metamorphic mineral locality information.

Paleotectonic maps, scales 1:5,000,000 and 1:10,000,000, as follows: Analysis of the Pennsylvanian System by E. D. McKee and others; Analysis of the Mississippian System by L. C. Craig and others.

Both analyses are completed and include maps showing total thickness of rocks of the two systems, thickness and lithofacies of the divisions of the systems, and distribution of rocks underlying and overlying the systems. In addition, interpretive maps show the transport direction of sediments, restored thicknesses, and tectonic development of the country during the two periods. Some maps show paleogeography and some show environments of deposition at selected times during the periods. The Analysis of the Pennsylvanian System is in press, and the Analysis of the Mississippian System is being prepared for publication.

Seismotectonic map of the eastern United States, scale 1:5,000,000, by J. B. Hadley and J. F. Devine; three sheets, one text pamphlet.

This black and white map was prepared by the USGS in cooperation with the Atomic Energy Commission (Hadley and Devine, 1974). It includes maps showing major geologic structures, the frequency of earthquake activity from 1800 to 1972, and an interpretation of the relationship of the seismicity to the geologic structures and tectonic provinces for the area east of the Mississippi River. The text gives a summary of the structural and seismic history of the area.

WATER-RESOURCE INVESTIGATIONS

The USGS conducts investigations, surveys, and research on the occurrence, quality, quantity, distribution, utilization, movement, and availability of the Nation's surface- and ground-water resources. This work includes (1) investigations of floods and droughts and their magnitude, frequency, and relation to climatic and physiographic factors; (2) evaluations of available waters in river basins and ground-water provinces, including assessment of water requirements for industrial, domestic, and agricultural purposes; (3) determinations of the chemical, physical, and biological characteristics of water resources and the relation of water quality and suspended-sediment load to various parts of the hydrologic cycle; and (4) studies of the interrelation of the water supply with climate, topography, vegetation, soils, and urbanization. One of the most important activities of the USGS is the systematic collection, analysis, and interpretation of data for evaluating the Nation's water resources. These data are computer processed for storage, retrieval, and dissemination of water information.

The USGS is responsible for coordinating national network and special water-data acquisition activities and maintaining a central catalog of water information for use by Federal agencies and other interested parties.

Research is conducted to improve the scientific basis of investigations in hydraulics, hydrology, instrumentation, and the chemical, physical, and biological characteristics of water.

Subjects currently under investigation or researched recently by the USGS include the following: (1) Properties of water—geochemistry, temperature, and water chemistry; (2) drainage, runoff, and watersheds—flood plains, floods, frozen ground, playas, and storm runoff; (3) evaporation, meteorology, and precipitation—droughts, evapotranspiration, glaciers, glaciology, ice and icing, snow, and transpiration; (4) flow, hydraulics, and streams—availability of water, base flow, channel morphology, culverts, drainage, flood-flow formulas, flood hazards, flood-inundation maps, fluid mechanics, gaging, geomorphology, highway drainage, hydraulic engineering, hydrodynamics, low flow, measurement of streamflow and time of travel under ice, mine acid drainage, overland flow, river basins, rivers, seepage, storm drainage, stratified flow, streamflow, stream classification, and water problems of the coal industry; (5) ground water—aquifers, artesian aquifers, artificial recharge, availability, carbonate-rock hydrology, connate water, core sampling, dispersion of contaminants, earthquake effects, electric-analog-model studies, flow, geochemistry, geochronology, geophysical logging, hot springs, hydraulics, hydrogeology, hydrologic properties, interpretations, investigations, levels, mapping, nuclear-explosion effects, nuclear-waste disposal, piezometric maps, pollution, pumping and pumpage rates, quality, quantity, radiocarbon dating, research, resistivity studies, saltwater intrusion, springs, subsidence of land, test-well drilling, thermal water, use of water, use of isotopes in investigations, waste disposal, and wells; (6) soil water—soil moisture, soil-water movement, and soil-water relationships; (7) lakes and reservoirs—biology and ecology, eutrophication, impoundments, lake levels, lake basins, limnology, ponds, and stratification; (8) water and plants—phreatophyte control, plant-water relationships, and tree rings; (9) erosion, sedimentation, and sediments—reservoir sedimentation, reservoir siltation, siltation, sediment control, and sediment transport; (10) quality of water—biological and ecological aspects of water chemistry, brine, chemical analysis, geochemistry, inorganic constituents, kinetics, radioactivity in water, salinity, solutes and solutions, and trace elements; (11) estuarine problems—biological and ecological problems, brackish water, distribution of sediments and wastes, tidal studies, transient flow, and upstream movement of saltwater; (12) water use—agricultural use, aluminum industry, copper industry, evaporation control, evapotranspiration control, hydroelectric use, industrial use, municipal use, petroleum industry, pulp and paper industry, rayon-and acetate-fiber industry, styrene-butadiene industry, surface- and ground- and waste-water use, syn-

thetic-rubber industry, and water requirements; (13) agriculture, irrigation, and pesticides—movement in streams and ground water of pesticides, water requirements, and water spreading; (14) water management—flood control, management of ground- and surface-water resources, and use of models; (15) water-pollution effects, water-pollution sources, and water quality—agricultural sources of pollution, detergents in water, effect of pollutants on aquatic life, industrial wastes, movement of pesticides and other pollutants in streams and ground water, pesticides in water, pollutant identification, radioactive rainout, saline-water intrusion, source of pollutants, temperature, and thermal pollution; (16) waste disposal—radioactive-waste disposal and waste-water disposal; (17) planning and water-resources development—development of ground- and surface-water resources, flood forecasting, river-basin planning, water budgets, and water supply; (18) water law; (19) environments—antarctic regions, arctic regions, arid lands, deltas, deserts, karst terrain, swamps, urban areas, and wetlands; (20) water-resource studies—appraisals, computer applications in water research, data processing, evaluation, hydrologic data, infrared application, instrumentation for hydrologic studies and resources research, interpretations, investigations, mapping of ground water, model studies, processing, publication, remote sensing, reports, research, stochastic hydrology, techniques for hydrologic studies and resources research, and telemetry; (21) corrosion—well casings; and (22) water cycle.

A significant part of USGS water-resource activities is providing scientific and technical assistance to other Federal agencies. When USGS interests are related to the interests of other agencies, USGS assistance contributes to the efficiency of their programs and encourages the maintenance of high standards of technical accomplishment.

The USGS develops ground- and surface-water technology and the technologies necessary for dealing with (1) the chemical, physical, and biological properties of water and (2) the interrelation of these water-quality properties within the environment.

During fiscal year 1975, data on streamflow were collected at about 7,480 continuous-record discharge stations and at about 9,000 lake- and reservoir-level sites and partial-record streamflow stations. About 12,000 maps of flood-prone areas in all States and Puerto Rico have been completed to date, and about 800 pamphlets covering areas susceptible to flooding have been published. Studies of the quality of surface water were expanded; there were approximately 4,970 water-quality stations in the United States and in outlying areas where surface water was analyzed by the USGS. Parameters measured include those of selected major cations and anions, specific conductance or dissolved solids, and pH. Other parameters, measured as needed, include trace elements, phosphorous and nitrogen compounds, detergents, pesticides, radioactivity, phenols, BOD, and coliform bacteria. Streamflow and water-temperature records were collected at 3,865 of the water-quality stations. Sediment data were obtained at over 1,070 locations.

Annually, about 500 USGS scientists report participation in areal water-resource studies and research on hydrologic principles, processes, and techniques. Nearly 300 of the studies in progress are classed as research projects. Of the current water-resource studies, about 350 are related to urban hydrology problems.

In fiscal year 1975, 511 areal appraisal studies were carried out. Maximum and mean areas of the studies were 1.5 million and 74,000 km^2, respectively. Total areal appraisal funding was about $21 million. Ground-water studies have been made or are currently in progress for about two-thirds of the Nation. In 1975, scheduled measurements of ground-water levels were made in about 28,000 wells, and periodic measurements were made in many thousands of other wells. Studies of saline-water aquifers, particularly as a medium for disposal of waste products, are becoming increasingly important, as are hydrologic principles governing the occurrence of brackish water in estuaries. Land subsidence due to ground-water depletion and the possibilities for induced ground-water recharge are under investigation in areas where the land surface has settled significantly.

The use of computers—in research studies of hydrologic systems, in expanding data-storage systems, and in quantifying many aspects of water-resource studies—continued to increase during fiscal year 1975. Records of about 280,000 station-yr of streamflow acquired at about 10,000 regular streamflow stations are stored on magnetic tape, and data on about 100,000 wells and springs have been entered in a new automated system for storage and retrieval of ground-water data. Digital-computer techniques are used to some extent in almost all the research projects, and new techniques and programs are being developed continually.

Final reports on USGS water-resource activities that were part of the IHD were concluded in 1975 following the close of the IHD in 1974.

The principal publications devoted to basic hydrologic data are in the following series of USGS 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 (1) the magnitude and frequency of floods for the entire country, (2) floods by drainage-basin areas, and (3) noteworthy floods for each year.

Requests for data on water use in the United States and in relatively small areas increased in 1975. The need to develop energy sources of various kinds in areas where industrial development has been nonexistent or minimal requires estimates of future water requirements in these areas and evaluation of the adequacy of the water resources to meet the demand. Studies are underway to improve methods for expanding the scope, intensity, and accuracy of water-use investigations.

Investigations describing the occurrence of water as a natural resource are given in the following sections for the four regions of the United States (fig. 4) used since 1973 by the USGS for administering the water-resource program.

NORTHEASTERN REGION

Intense rainfall on saturated soil in the Red Cedar River and Grand River basins resulted in severe flooding in the Lansing, Mich., metropolitan area during the period April 19–21, 1975. The peak flow of the Red Cedar River in the Lansing area was the highest since 1904, and that of the Grand River was the highest since 1947. Property losses were estimated to be $50 million.

Ideal melt conditions of the snowpack in Minnesota, which was reported to contain as much as 254 mm of water, reduced peak runoff to only a moderate flood hazard. Peak discharges resulting from the snowmelt were generally at or below 10-yr recurrence levels.

Model studies were begun to evaluate the effects of urbanization and other development on flows in the Susquehanna River basin in Pennsylvania. Particular emphasis will be placed on evaluating effects

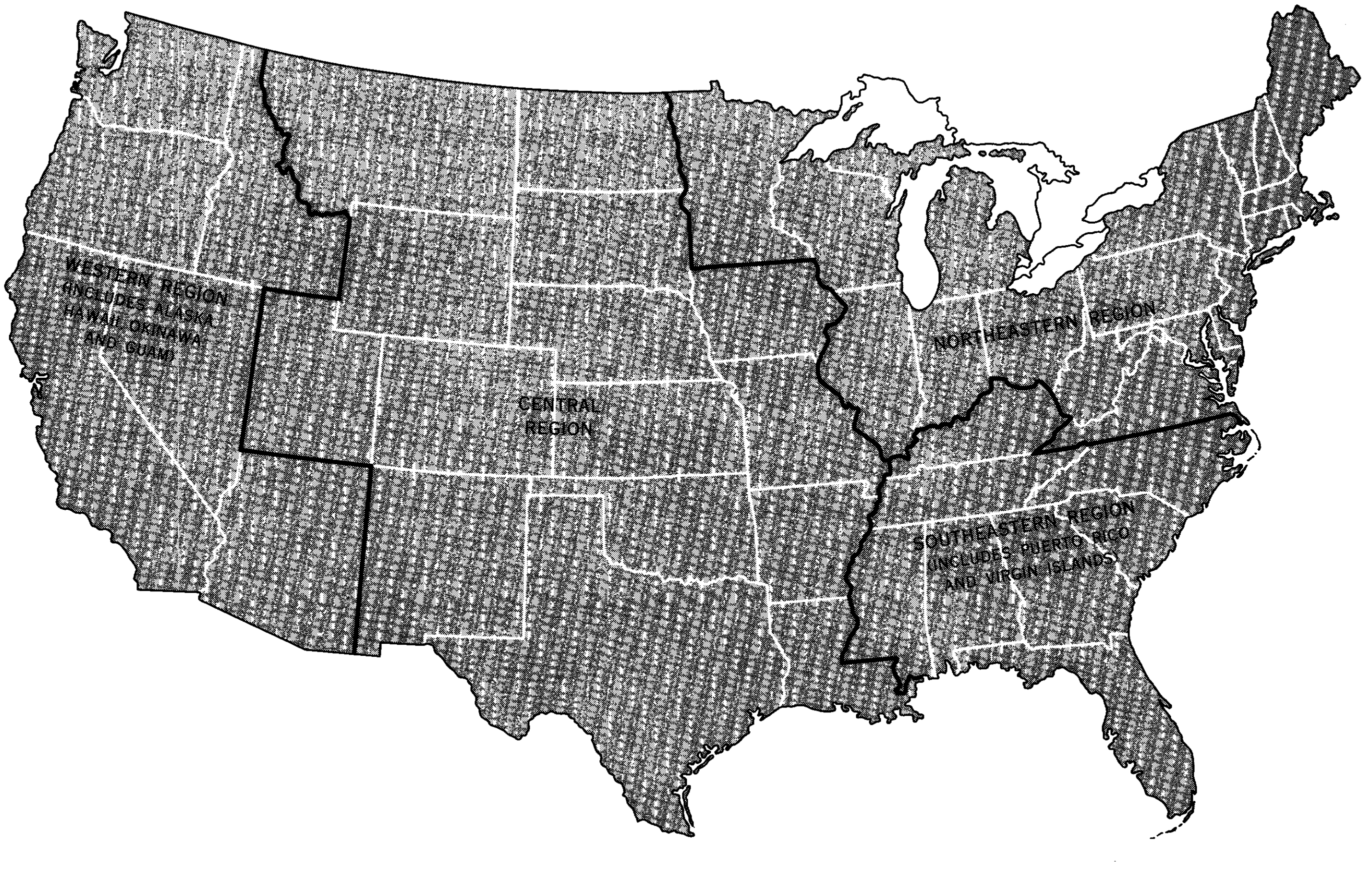


FIGURE 4.—Index map of the conterminous United States, showing areal subdivisions used in the discussion of water resources.

of reservoirs and powerplant operations. Secondary emphasis will be placed on providing flow-routing information for use in early warning of impending water shortages.

Landfill studies in the northeastern region continued, and increased emphasis was placed on tracing movement of organic compounds through shallow aquifers and toward streams. Studies were begun in Maine to assess or to index the trophic state of the State's lakes, which are a vast water resource.

The quality of streams in the upper part of the White River basin in Indiana was recently assessed in a comprehensive study. Besides water quality, the study included dynamic hydrology, geology, and socioeconomic factors.

An interdisciplinary study of the Conewago Lake drainage basin in Pennsylvania was made to document the present physical, chemical, and biological conditions of the 8-yr-old manmade lake and to postulate the relations between the natural environment of the basin and the chemical quality of streamflow and their effect on eutrophication.

A study evaluating the results of analyses of samples of water, bed material, fish, and soil collected in four small drainage basins in Pennsylvania was completed. Each basin represented a predominant land-use classification—forested, general farming, residential, and orchard. Data gathered during the study are being used to assess the occurrence of pesticide residues in different types of land-use areas.

A three-dimensional "hybrid" computer model of the Long Island aquifer system was used to study the impacts of various waste-disposal regimes on the hydrology. The model combines an analog technique of computation with digital methods of data processing and output. As sewers replace septic tanks and cesspools in more areas of Long Island, aquifer recharge is progressively reduced. The model was used to study the effect of recharge reduction on ground-water levels and streamflow in Nassau County and is currently being used to study the same effect in southwestern Suffolk County. Future studies will be islandwide and in addition will consider the effects of various regimes of artificial recharge and increased pumping of ground water. These studies will be closely coordinated with work funded by the EPA under Section 208 of the Federal Water Pollution Control Act, in which a comprehensive waste-disposal plan for the island is to be developed.

A three-dimensional analog model of the Indianapolis area was used to study the effects of increased pumpage on ground-water levels and streamflow. Increased utilization of ground water for the Indianapolis municipal supply has been proposed as an alternative to constructing a surface reservoir. Sustaining this additional ground-water pumpage is in question, as are probable effects on streamflow.

Similar studies of the effects of various regimes of water and waste management were made in Delaware, Massachusetts, Michigan, Minnesota, New Jersey, New York, Virginia, and Wisconsin. Digital models of aquifer systems have been used in all of these studies.

Work continued on a project to map the interface between saltwater and freshwater throughout West Virginia. Recent legislation requires that all oil and gas wells in West Virginia be cased through the freshwater zone. To enforce this regulation, the position of the base of freshwater must be determined. Data processing and map generation by computer have been used to prepare preliminary maps of each 15-min quadrangle in the State. Field checking of the maps will be completed in about 1½ yr. In addition to their immediate enforcement value, the maps will be valuable in assessing saline-water resources and the relation between connate brine and circulating fresh ground water in inland aquifer systems.

CONNECTICUT

Evaluation of stratified drift aquifers in south-central Connecticut

Hydrogeologic data collected from 140 test holes by F. P. Haeni and R. L. Melvin were used to evaluate the water-bearing characteristics of stratified drift aquifers in south-central Connecticut. Areas with significant saturated thickness and transmissivity have been identified in the Quinnipiac, Eight Mile, and Farm River valleys. Seismic surveys in the Farmington and Quinnipiac River valleys have indicated areas of thick stratified drift; these will be confirmed by subsequent test drilling.

INDIANA

Effect of landfills on water quality varies

R. A. Pettijohn reported that the results of a study of landfills in Marion County indicated that the effect of landfills on water quality varies from site to site. One landfill, which is in a ground-water discharge area, has little effect on ground-water quality beyond the perimeter of the refuse. A second, in a till area, evolves much gas (methane and carbon dioxide); leachate is brought to the surface by the gas and discharged into a stream. A third, on a flood plain, contaminates the deepest unconsolidated aquifer; a part

of the natural ground-water gradient is reversed because of heavy pumping. A fourth, also on the flood plain, contributes a high concentration of leachate to nearby ground-water bodies; the natural ground-water gradient of this landfill also has been reversed because of heavy pumping nearby.

MARYLAND

Ground-water resources of Harford County

Water in the metamorphic and igneous rocks of Harford County is unevenly distributed, and its availability is difficult to predict because the fracture system is complex and variable. According to L. J. Nutter, average well yields and specific capacities within various lithologic units seem to fall into broad groups that may constitute the basis for generalized "ground-water availability units." The units, however, have restricted use in planning because, within each unit, well yields normally range over more than an order of magnitude. Mapping of lineations on aerial photographs and field analyses of topography seem to be the most useful tools for selecting potentially high-yielding well sites. Lineations observed are normally topographic lows and straight reaches of streams whose orientation seems to be controlled mainly by joints and faults.

MASSACHUSETTS

Water resources of the Nashua River basin

Results of studies by B. P. Hansen and R. A. Brackley of the Nashua River basin showed that large supplies of water suitable for industrial or public supplies can be obtained from glacial deposits. Aquifers of glacial-outwash and ice-contact deposits lie primarily in the major stream valleys and can be divided into three levels of transmissivity—0 to 125 m^2/d, 125 to 370 m^2/d, and more than 370 m^2/d.

Time-of-travel investigations on the Shawsheen River, northeastern Massachusetts

Time-of-travel and longitudinal-dispersion studies on the Shawsheen River were made by F. B. Gay and Massachusetts Division of Water Pollution Control personnel; the base data are for use in the State's predictive water-quality computer-simulation model.

In the upper half of the river, a dispersion coefficient of 11.1 m^2/s was computed for a 9.56-km stretch of river having a discharge of 1.61 m^3/s, a fall of 3.14 m, and a well-defined stream channel that meanders on a 91.4-m-wide grassy flood plain. In the lower half of the river, a dispersion coefficient of 17.6 m^2/s was computed for a 9.69-km stretch of river having a discharge of 3.14 m^3/s, a fall of 12.13 m, and a gently curving pool and riffle channel. These coefficients are similar to those that R. G. Godfrey and B. J. Frederick (1963) determined for similar streams in Virginia.

The time required for the peak concentration of a contaminant to travel the entire length of the river (41.5 km) at a medium-range index discharge of 1.50 m^3/s was 3 d, whereas it would be in excess of 15½ d at a low-range index discharge of 0.20 m^3/s.

Graphic plots of river miles against the cumulative travel times of peak concentrations revealed that only one of the five impoundments along the stream significantly affects streamflow velocity and then only in the low range of discharges.

Preliminary results of an aquifer test in Truro

J. H. Guswa and C. J. Londquist reported that a preliminary analysis of data from an aquifer test in the town of Truro on Cape Cod indicates that average hydraulic conductivity is 20 m/d for the upper 36 m of the Wellfleet plain outwash deposits of Pleistocene age. Analyses of selected samples indicate that sand-particle size is generally medium but can range from very fine to coarse.

During pumping of a test well, water-level changes were measured in 10 observation wells screened at different depths in the aquifer. Specific yield and the ratio between the vertical hydraulic conductivity and the lateral hydraulic conductivity of the aquifer were estimated by comparing observed water-level changes with changes indicated by a digital radial-flow model developed by E. P. Weeks, who used an assumed hydraulic conductivity of 20 m/d and an assumed specific storage of 1.3×10^{-4} per metre. The best fits were obtained by using a specific yield of 0.10 and a ratio of vertical hydraulic conductivity to lateral hydraulic conductivity of 1:1 to 1:5. These conductivity ratios do not apply below a depth of 17 m.

Supplies of ground water readily available on Nantucket Island

On Nantucket Island, water occurs in the moraine along the northern part and in the sheet of glacial outwash to the south. The moraine contains much sand and gravel, and domestic water supplies can be obtained with little difficulty at most places through driven well points. The sand and gravel of the outwash yields water readily. According to E. H. Walker, the municipal water supply of the town of Nantucket is pumped from a field of 80 well points, which

can yield 3,780 m^3/d. A 30-cm-diameter well that provides part of the supply for Siasconset yielded 33 l/s with 2.7 m of drawdown. A few 15-cm-diameter wells drilled for irrigation have been reported to yield as much as 25 l/s.

Buried gravel is largest source of ground water along Connecticut River lowlands in Massachusetts

The principal aquifer in the Connecticut River lowlands of Massachusetts is a sheet of coarse sand and gravel that lies upon bedrock or till and under a blanket of silt, clay, and fine sand. Apparently, the sand and gravel was deposited at the edge of a shrinking glacier by many small streams of meltwater. The overlying fine-grained materials accumulated in postglacial Lake Hitchcock, which spread northward up the lowlands in the wake of melting ice.

According to E. H. Walker, S. W. Wandle, Jr., and W. W. Caswell, almost all public-supply wells in the lowlands tap the buried gravel. Yields of some wells exceed 63 l/s, even where the aquifer is only 3 m thick. The wells are artesian and, in some places, flow at the surface. Recharge enters the aquifer where the cover of fine-grained materials is thin and along the margins of the lowlands. The water is of good quality in most places (but may contain objectionable amounts of iron near swamps), is hard, and has a high sulfate content in some places.

Storage requirements for water supply in the Connecticut Valley

A regional storage analysis of the Connecticut River lowlands basin in Massachusetts by S. W. Wandle, Jr., W. W. Caswell, and E. H. Walker indicated that demands for water less than 5.5 $l\ s^{-1}\ km^{-2}$ can be satisfied by impounding the high flow each year for later release during low-flow periods (seasonal storage). Draft rates in excess of this amount can be met by storing water during wet years for later release during dry years (over-year storage). Storage requirement estimates for ungaged sites in the basin are indexed to the unit median-annual-minimum 7-d mean flow. Regional draft, storage, and frequency curves developed in this analysis provide a first approximation of the amount of storage required for given draft rates. Losses due to reservoir evaporation, sedimentation, and seepage are not included.

Water resources of southeastern Massachusetts

Reconnaissance geologic mapping and analyses of well data by R. E. Willey and J. R. Williams showed that the principal aquifers in the Seekonk to Wareham area of southeastern Massachusetts are localized in preglacial valleys cut in bedrock. Permeable materials, which form aquifers in these valleys, consist of deltaic, ice-contact, and outwash deposits. Ground water in parts of the study area is subject to saltwater contamination from seawater intrusion, ocean-storm flooding, and highway deicing chemicals. G. D. Tasker's analyses indicated that the 7-d 10-yr low flow of the streams in the area may be as much as 0.1 m^3/s.

MICHIGAN

Geology and hydrology for environmental planning in Delta County

The geologic and hydrologic characteristics of Delta County were studied by W. B. Fleck and C. J. Doonan, and a series of maps was prepared to aid planners and managers in evaluating land-use alternatives. Using the map series, Michigan Geological Survey personnel prepared a summary map showing areal suitability for landfill sites. Most of the more suitable areas are in the northwestern and southeastern parts of the county. Approximately half of the State-approved landfill sites are in areas that have been shown on maps to be favorable from geologic and hydrologic standpoints.

The study indicated that the Munising Sandstone of Cambrian age has a high potential for large withdrawals of water. The Trenton and Black River Limestones also are major sources of water; the upper parts have been drilled extensively for domestic water supplies. Except in the northeastern part of the county, Pleistocene deposits are generally less than 10 m thick and are of less importance for water supplies.

Geohydrology of Muskegon waste-water spray-irrigation site

A three-layered digital model was developed by W. B. Fleck to simulate ground-water flow characteristics in the vicinity of the Muskegon County waste-water treatment site. The model predicts the effects of future stresses on the ground-water system as the application of waste water by spray irrigation is increased. The 4,000-ha irrigation site at Muskegon is underlain by 75 to 90 m of Pleistocene deposits. The upper 20 m is a sand and gravel aquifer having a shallow water table. The aquifer is underlain by confining beds of silt and clay and some lenses of sand. The water-table gradient is westward toward Muskegon.

Underlying the Pleistocene deposits are the Michigan Formation,, the Marshall Formation, and the

Coldwater Shale, all of Mississippian age. The Marshall Formation is generally permeable and has a good water-producing potential, but some beds near the top of the Marshall Formation have been contaminated by gypsum leached from the overlying Michigan Formation.

Ground water in southeastern Michigan

An area of 14,000 km^2 in southeastern Michigan has a population of nearly 5 million. Although most water supplies for the area are obtained from streams and lakes, about 12 percent of the population uses ground water. Industrial, municipal, and rural-domestic supplies are obtained from glacial deposits and bedrock, according to F. R. Twenter.

Glacial deposits are as much as 150 m thick and have varying yields. Where deposits contain large amounts of sand and gravel, they may yield as much as 190 l/s. Ann Arbor, Waterford Township, and Ypsilanti Township, the largest users of ground water, individually withdraw 90 to 260 l/s. Where glacial deposits contain large amounts of clay, as they do in the eastern part of the area, yields are commonly less than 0.32 l/s.

Bedrock formations that are tapped as sources of water are the Saginaw Formation, the Marshall Formation, the Coldwater Shale, the Berea Sandstone, the Traverse Group, the Dundee Formation, the Detroit River Group, the Sylvania Sandstone, and the Bass Islands Dolomite. Of these, the Saginaw, Marshall, Berea, and Sylvania generally yield the greatest quantities of water—in some places as much as 20 l/s.

The chemical quality of ground water varies with well depth and rock type. At shallow depths, most water has dissolved-solids concentrations ranging from 200 to 700 mg/l. The dissolved-solids concentration increases as the well depth increases, and many deep wells yield water that is highly mineralized. In some places, shallow wells in bedrock also yield water that is highly mineralized. Most waters in southeastern Michigan are very hard (over 180 mg/l) and have iron concentrations ranging from 1 to 4 mg/l.

MINNESOTA

Digital models used to predict effects of irrigation on the hydrologic system

S. P. Larson (1975) used two digital models to predict water-level declines and sources of pumped water under different hypothetical plans of irrigation development of sandy soils overlying a surficial outwash aquifer. The model simulations constituted a significant part of a study of a sand-plain area near Appleton. Effects on the hydrologic system during 20 yr of withdrawing water from the outwash aquifer under (1) present (actual), (2) maximum (hypothetical), and (3) 50-percent maximum (hypothetical) irrigation development were depicted on maps and graphs. The models showed that the present annual withdrawal rate of 1.74 km^3 of water for irrigation would result in water-level declines of less than 0.9 m after 20 yr, whereas annual withdrawals of 10.4 km^3 would cause aquifer dewatering and decreased yields in some places. After a new state of equilibrium was established in response to withdrawals, most of the withdrawal would consist of diverted base flow from the Pomme de Terre River.

Ground water near Alexandria

M. S. McBride reported that digital models of two surface-outwash aquifers near Carlos and Parkers Prairie were completed.

Well yields greater than 0.06 m^3/s can be obtained in about one-third of the Carlos outwash area (73 km^2). Under maximum development, average water levels in the irrigated area should decline 0.6 to 2.4 m. The water would be derived almost entirely from the Long Prairie River.

Well yields greater than 0.06 m^3/s can be obtained from most of the Parkers Prairie outwash area (490 km^2). Under maximum development, average water levels in the irrigated area should decline 0.3 to 1 m. About half of the water would be derived from the stream and about half from salvaged evapotranspiration.

Outwash areas near Clotho, Urbank, Alexandria, and Rose City have less potential. Irrigation supplies may be available in places, but the saturated section of the surface aquifer is generally too thin for large-capacity wells.

Effects of dewatering a roadcut in Hennepin County

M. S. McBride completed a digital model designed to predict (1) the rate of pumping required to dewater an outwash sand and gravel deposit for highway construction at a railroad underpass and (2) the effects of that pumping.

The pumping rate needed to dewater the cut was predicted to be 0.057 m^3/s. At this rate, water levels in the cut area would decline to within 0.3 m of the design level within 3 to 6 weeks.

Effects of pumping on nearby Twin, Crystal, and Ryan Lakes were of particular concern. Under steady-state conditions, Twin and Crystal Lakes

would be the sources of 75 percent or more of the water pumped. If none of the water is returned to the lakes, declines in average lake levels can be expected to be within the following ranges: Twin Lakes, 0.06 to 0.3 m; Crystal Lake, 0.02 to 0.06 m; and Ryan Lake, 0.2 to 0.6 m.

Three analytical models also were used to predict the required pumping rate. This modeling was done to check the results of the digital model and to investigate the value of such models for making quick estimates of pumping rates. The results obtained (0.051, 0.062, and 0.059 m^3/s) were within 10 percent of the values given by the digital model.

Deep aquifers in Brooten-Belgrade area, west-central Minnesota

According to R. J. Wolf, test drilling in the Brooten-Belgrade and Lake Emily area indicated deeply buried, confined, coarse sand and gravel aquifers as thick as 15 m. In places (north of Belgrade, northwest of Brooten, east of Villard, and southwest of Lake Emily), the aquifers are thick and permeable enough to yield large quantities of water to wells. The aquifers are not extensive and sheetlike, however, but are rather narrow, elongate, and winding. Only by drilling closely spaced test holes can they be mapped in detail. Although large quantities of water may eventually be pumped from the aquifers, drawdown may be excessive locally, owing to nearby impermeable boundaries (clay till). Preliminary test results in the buried outwash aquifer northwest of Brooten indicate a transmissivity of 136 m^2/d and a hydraulic conductivity of 30 m/d.

Deposits of Cretaceous age were penetrated in many of the test holes, but sandstone was notably absent. Coarse water-bearing sand, gravel, and cobble beds were found at the bottoms of the Cretaceous rocks in some places but were generally not thick enough for large withdrawals of water.

Ground water in Park Rapids area

J. O. Helgesen studied water availability from a 1,943-km^2 surficial outwash aquifer in the Park Rapids area. Preliminary test augering has indicated that (1) the aquifer consists typically of fine sand to fine gravel, (2) depth to the water table ranges from about 0.9 m in much of the southern part of the area to over 9 m in the northern part, and (3) saturated thickness ranges generally from 3 to 9 m in the south and 6 to 18 m in the north.

Water resources of the St. Louis River watershed

Virtually all potable water in the St. Louis River watershed is from ground-water sources. Sand and gravel in the drift is the most favorable source, although Precambrian bedrock (primarily the Biwabik Iron-formation in the northern part of the watershed) is tapped where drift water is inadequate. Test augering in the northern part of the watershed indicated that the glacial-lake sand, typically very fine to fine and less than 3 m thick, is a poor source of water. According to G. F. Lindholm, D. W. Ericson, W. L. Broussard, and Marc Hult, outwash sand and gravel east of Eveleth is as thick as 15 m and, at least locally, is a good source of water. Large amounts of surface water are used in the iron-mining and wood-processing industries.

Water-supply sources in the Lake Superior watershed

Lake Superior provides a large quantity of water of good quality to nearby municipalities and industries. Elsewhere in the watershed, aquifers provide small to moderate amounts of water for domestic and farm uses. Thin clayey till in much of the area and thick lake clay in the central Nemadji River basin are generally inadequate for water supplies. Thick outwash and sandy-till deposits and the Hinckley Sandstone provide adequate yields for most purposes in the Nemadji basin. The Duluth Complex, volcanic flows, and associated rocks in the remainder of the watershed are the principal aquifers and yield from 0.06 to 1.26 l/s to domestic and farm wells generally less than 5.1 m deep, according to P. G. Olcott, P. E. Felsheim, W. L. Broussard, and D. W. Ericson.

Reconnaissance of sand-plain aquifers

Surficial sand deposits cover more than 31,000 km^2 in Minnesota. Studies of the availability of water have been made in seven sand-plain areas. These studies cover 12 percent (4,000 km^2) of the deposits in the State. H. W. Anderson, Jr., evaluated data from the remaining 88 percent of the deposits.

Data on water use for irrigation, irrigation permits, saturated thickness, area of surficial sand deposits, observation wells, water in storage, and range in well yields, collected from many sources, are being processed for manipulation by the System-2000 database management system.

Low-flow variations in southeastern Minnesota

K. L. Lindskov found that in southeastern Minnesota the unit discharge for a drought of 7 consecutive days recurring on an average of once every 10 yr decreases as the basin size increases. Figure 5 plots the unit discharges against the drainage areas for 26 tributaries draining into the Mississippi River below St. Paul and above Lock and Dam 8. The rela-

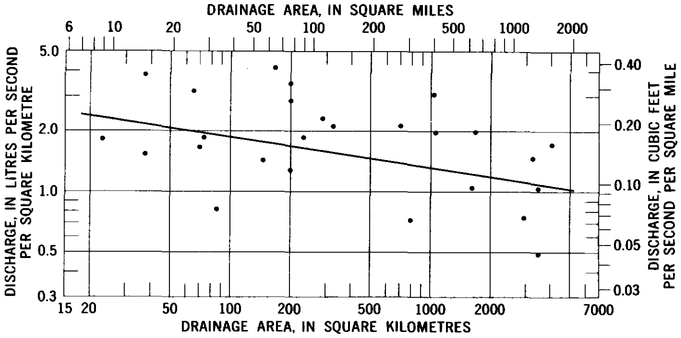


FIGURE 5.—Unit discharges of 7-d droughts of 10-yr duration in Mississippi tributaries below St. Paul, Minn., in relation to drainage areas.

tionship on figure 5 shows that the unit discharge of a 7-d drought of 10-yr severity varies as the −0.15 power of the drainage area; that is, data indicate that the discharge is proportional to the drainage area to the 0.85 power.

The area studied is part of the Wisconsin Driftless section of the Central Lowland province and is covered by loess overlying Paleozoic limestone, sandstone, and dolomite.

NEW JERSEY

Saline ground water

J. E. Luzier and R. L. Walker, Jr., investigated the vertical head distribution, salinity, and temperature variation of water in a well tapping the Potomac-Raritan-Magothy aquifer system of the Coastal Plain. An abandoned 1,127-m oil test hole was jet perforated and tested at five zones from depths of 640 to 1,036 m. The altitude of the water level at each of the zones, adjusted for density, temperature, and pressure, ranged from −5 m at 640 m to 1,036 m. Chloride concentration increased from 11,000 mg/l at 640 m to 27,000 mg/l at 1,036 m. Temperature profiles before testing were concave downward, this condition suggesting upward gradients and, therefore, upward leakage. After the last pumping test at 640 m, repeated temperature logging showed a rapid thermal recovery in the well bore (7°C within 3 d). After 28 d, the temperature was within 0.1°C of the original thermal gradient.

Computer model of outwash valley-fill aquifer

A computer model was developed to simulate a glacial-outwash aquifer in Morris and Essex Counties. The outwash was deposited in an interconnected series of five valleys during the last glaciation. Calibration of the model was based upon comparison of computed water-level declines with declines measured in 12 observation wells during one or more periods, ranging from 3 to 19 yr, since 1953. Harold Meisler used the calibrated model to determine the quantity of water available from the valley-fill aquifer. On the basis of the criterion that water levels would stabilize at least 9 m above the base of the aquifer, the model indicated that pumpage of approximately 1.8 m^3/s, about 40 percent more than the 1972–73 rate, could be obtained on a continuous basis. All of the increase would have to come from two of the valleys, as the other three are probably already fully developed.

Digital simulation of the Wenonah-Mount Laurel aquifer

A geohydrologic study by Bronius Nemickas of the confined Wenonah-Mount Laurel aquifer in the Coastal Plain of New Jersey involved the calibration of a digital model. The model indicated that two-thirds of the head decline in the Wenonah-Mount Laurel aquifer during the simulation period (1959–70) is related to withdrawals from the underlying Englishtown aquifer. Although the aquifers are separated by a confining unit ranging from 6 to 70 m in thickness, the head differential induces leakage from the Wenonah-Mount Laurel aquifer to the Englishtown aquifer.

NEW YORK

Aquifers defined in Dale Valley, western New York

Intensive study of water in the glacial drift of Dale Valley, a glacially scoured trough in western New York, revealed two aquifers, according to A. D. Randall. The deeper aquifer, 3 to 7 m of sand and gravel buried beneath 30 m or more of fine-grained lake deposits, is hydraulically continuous for about 5 km along the valley axis. The shallower aquifer, 2 to 3 m of gravelly alluvium generally less than 4.5 m below land surface, is in hydraulic contact with small streams in the valley. Chloride concentrations in the deeper aquifer are generally betwen 5 and 25 mg/l. Chloride concentrations as high as 1,100 mg/l in an area of industrial development probably were due to migration of water from the bedrock. A digital model is being fitted to hydraulic data for the deeper aquifer.

Water table in Long Island, March 1974

According to water-table and net-change maps prepared by E. J. Koszalka, ground-water levels have risen a maximum of 3 m in the central part of Long Island since March 1970. The rise is attributed to higher than normal precipitation during 1972–73. Water levels in a sewered and highly urbanized area

of Nassau County have declined a maximum of 1.2 m since 1970. This decline, notwithstanding the higher than normal 1972–73 precipitation, resulted from the combined effects of ground-water withdrawals and sewering.

PENNSYLVANIA

Occurrence of saline water in northwestern Crawford County

Much of northwestern Crawford County is underlain by rocks of Devonian age that contain saline water at depths less than 30 m below the land surface, but few quantitative salinity data are available. G. R. Schiner and J. T. Gallaher tested a 45-m-deep hole and determined the following:

1. Water at a depth of 5.5 m had a chloride content of 30 mg/l and a specific conductance of 750 μmho.
2. To a depth of 15 m, chloride content and specific conductance remained about the same.
3. At 20.7 m, however, chloride content rose to 425 mg/l, and specific conductance rose to 2,400 μmho.
4. At 30.5 m, chloride content rose to 600 mg/l, and specific conductance rose to 4,000 μmho.
5. At 45 m, chloride content rose to 2,575 mg/l, and specific conductance rose to 7,000 μmho.

Basement flooding by ground water

Results of a recently completed study by D. J. Growitz indicated that basement flooding in the Kingston area has been caused by ground water. During years of average precipitation, approximately 25 percent of the 15.5-km^2 study area can experience either seasonal or constant flooding problems. The area is underlain by a complex ground-water reservoir consisting of 30.5 m of unconsolidated deposits overlying conglomerate, sandstone, shale, and anthracite coal beds; these coal beds have been partly or wholly removed by mining, depending on their accessibility.

In addition to the low relief of the Kingston area and its proximity to the Susquehanna River, both of which foster a high water table, two other factors also contribute significantly toward creating flooding problems: (1) Recovery of water levels after cessation of deep mining and dewatering pumping and (2) land subsidence.

Possible means (other than pumping) of lowering the high water table in problem areas include (1) gravity-drain wells, (2) gravity-overflow wells, (3) sealing the channel of a local creek, and (4) a subsurface drainage ditch.

VIRGINIA

Chemical quality of ground water in the Coastal Plain

Results of S. M. Rogers' ground-water-quality investigation in the Coastal Plain of Virginia showed that the chemical composition of water from each major aquifer is distinctly characteristic of that aquifer. Water type changes from bicarbonate to chloride in two of the major aquifers. West of the transition zone in the Tertiary sediments, the water type is calcium-magnesium bicarbonate; in the Cretaceous aquifer, it is sodium bicarbonate. East of the transition zone, all ground water is predominately a chloride type, having at least 250 mg/l of chloride. The transition zone seems to be narrow and extends in a generally north-south direction. Further study will be necessary to delineate the nature and extent of the freshwater-saltwater interface.

Water-level changes in southeastern Virginia

Ground-water use at a large industrial plant in Franklin was drastically curtailed between July 21 and August 23, 1974; pumpage was reduced from approximately 1.5 m^3/s to 0.13 m^3/s.

Near the center of the well field, the water level recovered about 14 m; it recovered about 9 m at the northern and southern extremities of the field. Water-level recoveries of 1.2 m and 0.5 m were noted in wells 12 km southeast and 19.3 km northwest of the pumping center.

O. J. Cosner used this information to evaluate the accuracy of a digital model of the Lower Cretaceous aquifer.

WEST VIRGINIA

Acid water only local in the Coal River basin

Periodic sampling of stream water at 14 sites in the Coal River basin for nearly 2 yr provided key data on the variation of stream-water quality with time and discharge. An additional 100 sites were sampled at low flow and again at high flow. According to J. L. Chisholm, chemical analyses of all samples indicated acidity only locally in headwaters. Biologic data support this finding; most phytoplankton found in the streams are those common to alkaline water.

In Boone County, which constitutes most of the basin, coal was mined from 1846 to 1861 and from 1909 to the present; therefore, the stream water could be expected to be acid, but it is not. The reason for the lack of widespread acidity is not fully understood, but it is probably a combination of natural

limestone neutralization and man's activities in water treatment and mine safety.

Ground-water hydrology of Berkeley County

According to W. A. Hobba, Jr., more than 350 ground-water levels were determined, water samples were collected, and 13 streamflow measurements were made in Berkeley County during a 2-week period of declining water levels in July and August 1973. In January 1974, some sites were remeasured during a period of rising ground-water levels, and water samples were collected and analyzed for nitrate and bacteria. A similar study was made in adjacent Jefferson County during a 2-week period in August and September 1974. Water levels in the carbonate rocks of these counties fluctuate considerably, as does the chemical quality of the ground water, so that the water-table and water-quality maps prepared from the collected data are representative only for the time of measurement. Specific conductance ranged from 10 to 1,400 μmho, carbonate hardness ranged from 3 to 700 mg/l, nitrate concentration ranged from 0 to 143 mg/l, and chloride concentration ranged from 1 to 255 mg/l.

SOUTHEASTERN REGION

Investigations of the demand for water, disposal of wastes, and changes in land use related to water resources continued to be emphasized in the southeastern region. Data collection and analyses of data by modeling techniques are being intensified to provide the information necessary for the maximum utilization of water resources to meet immediate and long-term needs.

In Florida, several studies are underway to increase recharge to stressed aquifers by using induced infiltration, water spreading, and connector wells between shallow and deep aquifers as means of meeting increased water demand. Florida is also studying the surface and subsurface disposal of solid and liquid wastes involving landfills, ponds, water spreading, and disposal wells. In Tennessee, the delineation of fracture traces in limestone areas from aerial photographs has enabled investigators to select areas where yields to wells may be greater than normally expected. A deterministic flow model was developed for the Chowan River Estuary in North Carolina. A flow and water-quality model of the lower Santee River in South Carolina is being developed in anticipation of a major rediversion of flow from the Cooper River.

ALABAMA

Water problems related to coal mining

A. L. Knight, in an investigation to document water problems associated with coal mining in Alabama, canvassed all sources of information in USGS files and those of other agencies such as the U.S. Bureau of Mines, EPA, the Mining Enforcement and Safety Administration, the Geological Survey of Alabama, and the Alabama Water Improvement Commission. Information compiled thus far indicates that dewatering has seriously affected the availability of ground water for municipal and domestic supplies and, in some areas, that land subsidence has occurred. Also, drainage basins have been altered quite extensively, and the flow characteristics of streams have changed.

A research of litigation associated with coal mining has provided information that not only defined the various problems but also proved to be an excellent means of documenting their histories. For example, cases involving spoil banks and "foul water" associated with coal mining were recorded as early as 1892.

Chemical analyses of water collected from some streams draining coal-mine areas indicate that the chemical composition of water in the stream has been altered. Water from strip pits, spoil banks, and coal-washing operations contains highly mineralized acid water; pH values for water in streams near extensively mined areas commonly range from 2.1 to 5.

A study of 1:130,000-scale high-altitude color infrared photographs covering most of seven counties in which coal is mined shows that there is extensive strip mining in more than 2,330 km^2.

Water-quality network—contaminated municipal supply

In 1972 a network of five wells and five springs was established as part of a cooperative program with the Geological Survey of Alabama to determine the baseline of chemical character, including minor elements of ground water, in the State. Some of these wells and springs were used as sources of municipal water supply.

On March 12, 1974, a water sample was collected from a city well at Irondale in Jefferson County. According to W. J. Powell, the minor-element analysis of the water sample indicated a chromium content of 55 mg/l. On July 25, 1974, when the well was resampled, the chromium content had increased to 140 mg/l. The results of these analyses were brought to the attention of the Alabama Department of Public Health, and a resampling of the water from this well

by that agency and EPA verified a high chromium content. The Alabama Department of Public Health discontinued use of the well as a source of municipal supply until an investigation could be made to determine the source of the contaminant.

Fluorescein dye used to solve a highway problem

As a part of an environmentally oriented cooperative project with the Alabama Highway Department, J. C. Scott used fluorescein dye to help solve a highway problem. A slide in fill beneath Interstate Highway 59 in Etowah County resulted in failure of a section of pavement that cost more than $1 million to repair. A study showed that the slide was caused primarily by water moving into the base of the relatively impermeable fill. Water pressure and the lubricating properties of the water eventually caused the fill to move and the pavement to fail. Fluorescein dye was introduced into a small "swallow hole" in a ditch about 300 m northeast of and about 45 m above the base of the fill. A large amount of dye appeared at the base of the fill after about 48 h. On the basis of these findings and the geologic and hydrologic conditions in the area, recommendations for diverting the water away from the slide area were submitted to the highway department.

FLORIDA

Low well yields and low base flows of streams in parts of Gadsden County

The Floridan aquifer, the principal source of potable ground water in Florida, is low in permeability in northern and central Gadsden County; generally, the aquifer is capable of yielding water in usable quantities to domestic wells but not to large-capacity municipal and irrigation wells. According to C. A. Pascale, except for water from wells deeper than 200 m, ground water is of high enough quality to be acceptable for most uses; the dissolved-solids content increases substantially at greater depths. Ground-water levels in the county range from 30 to 70 m below land surface, and in some areas there are large differences in water levels in nearby wells, this fact suggesting that there are multiple subaquifers within the Floridan aquifer.

Base flows of streams in northern and central Gadsden County are relatively low in comparison with those of most streams in northwestern Florida. Dissolved-solids concentrations range from 30 to 70 mg/l, and color ranges from 20 to 90 units.

Evaluation of changing land-use practices in the Myakka River basin

Tatum Sawgrass is a large surface-depression area of the upper Myakka River basin in Sarasota and Manatee Counties. The main channel of the Myakka River includes the southern part of Tatum Sawgrass. Under previous natural conditions, Tatum Sawgrass provided a significant amount of floodwater storage for the Myakka River and thereby attenuated flood peaks and flood heights in downstream reaches. Recent construction of a complex system of manmade dikes across the mouth of Tatum Sawgrass for agricultural purposes severely restricted use of this natural surface depression as a flood-storage area. As a result, according to J. F. Turner, Jr., flood-peak discharges and flood heights were increased in downstream reaches of the Myakka River.

Effects of strip mining on shallow aquifer systems in phosphate district

A 4,000-km^2 area incorporating parts of Hillsborough and Polk Counties is being strip mined for phosphate ore. Pumpage from the Floridan aquifer for municipal, agricultural, and industrial use has caused long-term withdrawals from storage and water-level declines of as much as 30 m.

The deposits that overlie the Floridan aquifer in this area are more than 45 m thick and contain as many as three shallow aquifers. C. B. Hutchinson concluded from preliminary results of aquifer tests and water-quality analyses that the shallow aquifers may be of limited use as a water supply. In some areas, transmissivities of the aquifers are low, and radium concentrations are above acceptable limits for human consumption.

Studies of the coastal springs in west-central Florida

Flows of the short, spring-fed Chassahowitzka, Homosassa, and Crystal Rivers are strongly affected by tides, and saltwater may migrate upstream to the areas of discharging springs. However, measurements of migration of the salt wedge in the Weeki Wachee River indicated to W. C. Sinclair and C. L. Goetz that the high velocity of flow and the narrowness of the channel restrict saltwater encroachment to the lower 2 km of river channel during normal tides.

In a companion study, J. D. Hunn reported that results of analyses of water samples indicated that offshore and shoreline sinks along the gulf coast in Citrus and Hernando Counties do not discharge freshwater except during periods of extremely heavy rainfall.

Aquifer recharge evaluated in the Green Swamp area

An area having good potential for downward leakage was delineated by H. F. Grubb in the eastern half of the Green Swamp area of central Florida. The presence of a very fine to coarse-grained sand aquifer was noted from analyses of geophysical logs and nearly 1,700 m of continuous unconsolidated core obtained from drilling through post-Miocene and Miocene sediments to the top of the underlying Floridan aquifer during the summer of 1974. Generally, the sand aquifer was absent, and most of the unconsolidated sediments were clay over the western part of the area, and thus the potential for downward leakage to the Floridan aquifer was limited to a few isolated areas where sand was present. Natural downward leakage is limited owing to the high potentiometric surface over most of the Green Swamp area. Practical benefits to be gained from this downward leakage potential are dependent upon application of a stress to the Floridan aquifer that would lower the potentiometric surface.

Potential for recharge in Volusia County

After a test drilling program directed by J. O. Kimrey that confirmed a good hydraulic connection between the water table and the Floridan aquifer in central Volusia County, a digital modeling study of the area was begun by P. W. Bush. Bush used the USGS's digital model (Pinder-Trescott model) for aquifer evaluation to complete a steady-state calibration for a 1,600-km^2 area of Volusia County; the model will reproduce the natural, unstressed potentiometric surface of the Floridan aquifer. Transmissivities and confining-layer permeabilities dictated by the model in the area of a future well field are on the order of 1,250 m^2/d and 3×10^{-3} m/d, respectively.

High nutrient concentration largely confined to the conservation areas canal system

B. F. McPherson and H. C. Mattraw, Jr., found that the nutrients in organic nitrogen and phosphorus (B. G. Waller, 1975) are largely removed from canal water as it moves from a canal into the Everglades marsh. Within several hundred metres of the canals, nutrient concentrations approach the background level of those found in the interior marshes of conservation areas. However, most of the nutrient-rich water pumped into the conservation areas stays in canals, where uptake is less than in the shallow marshes.

Physical characteristics of a shallow aquifer defined by test holes and wells

The thickness, relative permeability, and water-table surface of the shallow aquifer in Palm Beach County were investigated by H. G. Rodis, L. F. Land, and J. J. Schneider. The aquifer is thickest (about 140 m) in the southeastern part of the county and thinnest (about 45 m) in the western part of the county. Data also show that the aquifer is most permeable in the southeastern part and becomes less permeable as it thins because of the increased content of finer sand, silt, and marl. These finer materials also occur at depth and make the lower third much less permeable than the top two-thirds. The water-table surface is highest in the conservation and wildlife areas near the center of the county. In eastern areas of the county, the water table conforms generally to the topography, but, in the southwestern part, most water-table fluctuations are controlled by canal pumpage.

Potentiometric levels of Floridan aquifer in Seminole County

C. H. Tibbals (1975) reported that ground-water use is greatest in southwestern Seminole County, an area of rapid urbanization, and in the central and northwestern parts of the county, where large amounts of water are used to irrigate vegetable crops. From 1955 to 1974, potentiometric levels of the Floridan aquifer have declined about 1.5 m in southwestern Seminole County and about 0.6 m in the agricultural areas. The chloride concentration has remained virtually unchanged in southwestern Seminole County. Slight declines in the potentiometric level in the agricultural areas generally result in increased chloride concentration because these are areas where the interface between saltwater and freshwater occurs at a relatively shallow depth.

Water resources of Manatee County

The western part of Manatee County has rapidly changed from an agricultural and retirement area to an urban industrial area; in so doing, it has created water-resource problems for the area. To evaluate the regional effects of development, a hydrologic data base for surface and ground water was established.

A preliminary analysis of an aquifer test within a proposed phosphate-mining area in eastern Manatee County was made by D. P. Brown and A. F. Robertson. The lower Ocala and upper Avon Park zones (229 to 381 m below land surface) of the Floridan aquifer were pumped for 5 d at a rate of 142 l/s. Maximum estimated values of the hydraulic parameters are: transmissivity, 6,210 m^2/d; storage coefficient,

1×10^{-3}; and leakance, 6.7×10^{-4}. Aquifer test data definitely indicate anisotropy, but additional analyses will be necessary to determine the axes and values of the hydraulic parameters that would result from this concept.

Connector well completed in DeSoto County

W. E. Wilson III and C. B. Hutchinson reported that a connector well was drilled at a 9,700-ha citrus grove in northeastern DeSoto County. The well connects the surficial sand aquifer with the deep, highly transmissive Florida limestone aquifer. Because of natural head differences, water moves by gravity flow from the upper aquifer into the lower aquifer.

The connector well has two 25-cm-diameter sand-packed screens (one in the upper unit and the other in the lower unit of the sand aquifer), about 120 m of 15-cm casing through confining beds and a secondary limestone aquifer, and about 76 m of open hole in the Floridan aquifer.

The expected recharge rate of the connector well is about 10.7 l/s under steady-state conditions. The well captures water normally lost by runoff.

Treatment of brackish ground water best outlook for continuing supply for the Venice-Englewood area

According to Horace Sutcliffe, Jr., limited quantities of ground water suitable for public or domestic supplies are available in some parts of the Venice-Englewood area. However, treatment of brackish ground water will be necesary to provide a continuing supply for the area's rapidly expanding population. Two reverse-osmosis plants having capacities of as much as 0.09 m^3/s are either operating or under construction. One area between Englewood and Venice, yet to be investigated, might yield an additional 0.13 to 0.18 m^3/s of treatable water to the district.

Hydrology of the sand and gravel aquifer in central and southern Escambia County

A sand and gravel aquifer is the only freshwater aquifer in the Pensacola area. Although its thickness locally exceeds 300 m in Escambia and Santa Rosa Counties, most of the clean sand layers are no more than 140 m below land surface in the Pensacola area, according to Henry Trapp, Jr. (1974). Ground water moves southward from an area of higher head in northern Escambia County, but virtually none of it reaches Pensacola. A reversal in gradient represented by the combination of (1) the large compound cone of depression produced by industrial pumping at Cantonment and (2) the natural depressions associated with stream valleys form a barrier to further southward movement. Virtually all of the ground water pumped from wells south of the reversal in gradient comes from local recharge.

The unadjusted carbon-14 age of a sample of freshwater from a well in the sand and gravel aquifer was found to be 14,050 yr. According to L. J. Schroder II (oral commun., 1974), the most probable corrected age is 8,200 to 9,600 yr. The age range reflects the uncertainty in the values for the soil, air, and limestone factors required for correction.

The 98-m-deep well is located at Fort Pickens on an island in Pensacola Bay. Other wells on the island have yielded saline water from the same depth. The age of the water suggests that the well taps an isolated lens of fossil freshwater that entered the aquifer when the sea level was lower.

Saltwater intrusion endangers some coastal municipal wells in Palm Beach County

The extent of saltwater intrusion near municipal coastal wells in Palm Beach County was defined in an investigation by H. G. Rodis, L. F. Land, J. J. Schneider, and W. B. Scott. All well-field areas were found to have been intruded to some extent. There is no immediate threat to well fields at Riviera Beach, West Palm Beach, and Lake Worth, where the distance to the saltwater wedge is about 1 km. Lantana, Boynton Beach, Delray Beach, and Boca Raton also appear to be in no immediate danger, although the wedge is about 0.5 to 1 km from their wells. However, at Juno Beach and Tequesta, the wedge is less than 200 m from wells.

Ground-water resources of DeSoto and Hardee Counties

Results of a study of the hydrogeologic framework of the middle Peace River basin by W. E. Wilson III indicated that ground water in the area is obtained from the surficial aquifer and the Floridan aquifer. The surficial aquifer consists principally of fine sand; the estimated average transmissivity is 120 m^2/d. Wells yield 1 l/s or more for domestic, lawn-irrigation, and stock-watering supplies.

The Floridan aquifer consists of two units, both primarily limestone and dolostone. The average thickness of the upper unit (Hawthorn Formation and the limestone unit of the Tampa Limestone) is about 55 m. Near Arcadia, transmissivity is probably more than 280 m^2/d. Wells yield from 1 l/s to more than 6 l/s and are used mostly for domestic supplies. The average thickness of the lower unit (Suwanee Limestone, Ocala Group, Avon Park Limestone) is more than 275 m. The few wells that are open to the lower units yield more than 63 l/s.

A confining bed of clay and marl separates the surficial aquifer and the upper unit of the Floridan aquifer. In much of the area, the sand and clay unit of the Tampa Limestone is a confining bed between the upper and lower units of the Floridan aquifer.

Artificial-recharge study concluded

The surficial sand aquifer overlying the limestone Floridan aquifer in the Hillsborough-Pasco-Pinellas tricounty area will be a key factor in the management of the area's water resources. According to W. C. Sinclair, experiments with several recharge techniques indicate that the most successful would be a network of subsurface drain tiles that provide flow of water by gravity to wells open to the Floridan aquifer. Such a system would divert more water to the Floridan aquifer while maintaining the water table at a level low enough to facilitate infiltration. Tests of an experimental drain field indicate that long-term flow of about 375 m^3 d^{-1} ha^{-1} can be expected under conditions in the study area. In the area affected by drainage, the water table is maintained about 1 m lower than it is in undrained control areas. Specific yield of the surficial sand is about 0.24; thus, a hectare of land underlain by drain tile may be infiltrated by 2,400 m^3 more water than an undrained hectare.

Water availability in an expanding urban area

According to H. J. McCoy (1974; B. F. McPherson and H. J. McCoy, 1974), the safe yield of the coastal aquifer in Collier County was reached during the 1973–74 dry season. Additional water supplies for the 1974–75 dry period were obtained by pumping from a borrow pit. This additional water should suffice for the next 2 yr until the large well field, 24 km inland, is completed and hooked up to the distribution system.

Landfill study in Hillsborough County

Monitoring of the water quality at a landfill near Eureka Springs in eastern Hillsborough County indicates movement of leachate through shallow aquifers toward residences bordering the eastern side of the site. According to Mario Fernandez, Jr., no noticeable changes have occurred in the chemical quality of water from the deep limestone aquifer at the landfill site and at nearby residences. Monitoring of a landfill near Rocky Creek in the northwestern part of the county indicates no lateral or vertical movement of contaminants from that site.

Testing water-management schemes by an analog model

E. H. Cordes reported that two concepts for managing the Biscayne aquifer ground-water system were tested on the USGS's electric-analog model at Reston, Va. One model study proposed the addition of a second control structure on the Smoke Creek Canal, about 19 km inland from the coast. This secondary control would operate in response to upstream and downstream water levels and, in addition, would simulate flow criteria.

A second modeling concept, called "Forward Pumping," was programed to test the utility of creating ground-water storage by pumping from the aquifer in anticipation of periods of abundant rainfall that would recharge the system.

Protection of water resources by management

Broward County's largest supplier of fresh ground water—Fort Lauderdale's Prospect well field—increased withdrawals during the critically dry period of 1973–74 without experiencing an inland advance of the nearby saltwater front, according to H. J. McCoy and C. B. Sherwood, Jr. This task was accomplished by using an almost completed feeder canal to furnish enough replenishment water to the aquifer to maintain freshwater heads at levels high enough to retard saltwater movement inland and by locating additional supply wells as far inland as possible from the saltwater front.

GEORGIA

Surface geophysical methods aid ground-water study

Surface geophysical methods were used for the first time in a hydrologic investigation of the Paleozoic strata of Georgia by C. W. Cressler and H. E. Blanchard, Jr. Resistivity and gravity surveys have been used to delineate buried hydrologic units, to determine their thickness, and to detect unexposed geologic structures commonly associated with high permeability.

Gravity data for Cartersville in Bartow County indicate that a string of industrial wells having unusually high yields—as much as 220 l/s—is located along a buried reverse fault. The fault, which uplifted quartzite of the Chilhowee Group into contact with the Shady Dolomite, probably has a displacement of nearly 100 m. Weathering in the fault zone ranges from 30 to more than 60 m deep. Deep weathering of the Shady Dolomite has produced a highly permeable zone that yields large volumes of water to wells.

A gravity survey conducted 6 km north of Cartersville indicates that a large industrial park, previ-

ously thought to lie on shale and sandstone of the Rome Formation, is underlain by dolomite of the Conasauga Formation. Gravity data show that, over a broad area, a flat thrust fault brought shale and sandstone of the older Rome Formation westward into a position over the dolomite of the Conasauga. Erosion of the thrust sheet has exposed the dolomite at the industrial park and resulted in a window through the fault 0.4 km to the north. The dolomite seems to be nearly 100 m thick, and its potential for large well yields is good.

Test well reveals water-quality anomaly

A study of well cuttings from a USGS test well in the Valdosta area shows that the principal artesian aquifer, a limestone and a dolomitic limestone of Tertiary age, can be divided into two distinct water-bearing zones. R. E. Krause (USGS) and T. M. Kramer (Georgia Department of Natural Resources) found that the upper zone contains a calcium-bicarbonate-type water with a dissolved-solids concentration of less than 250 mg/l, whereas the lower zone contains a calcium-magnesium-sulfate-type water with a dissolved-solids concentration greater than 2,800 mg/l. A 15- to 30-m-thick layer of dense, less permeable limestone separates the two zones. Tertiary tectonism has fractured this confining bed, and differences in hydraulic head permit migration of brackish water into the freshwater zone, principally in areas where heavy pumpage causes greater head differentials.

Cuttings from nearby oil test wells and preliminary examinations of cores from the USGS test well indicate the presence of evaporite deposits in the lower zone. These deposits include calcium sulfate minerals, principally gypsum, and they probably are the source of the high dissolved-solids sulfate-type water. Intervals below gypsiferous zones within the lower water-bearing zone yield water high in strontium concentration, probably due to celestite.

KENTUCKY

Wells tapping limestone in north-central Kentucky

In the Elizabethtown area of north-central Kentucky, T. W. Lambert found that the average well is 28 m deep and contains 16 m of water. The depth of wells ranges from 9 to 102 m. The deepest wells are in areas of surficial sand and clay deposits that were derived from the weathering of sandstone and limestone of Mississippian age. Most wells tap the St. Louis Limestone of Mississippian age and yield water having a conductance of 390 μmho at 25°C. Wells that tap the basal St. Louis Limestone yield water that has conductance greater than 1,000 μmho at 25°C and contains sulfate in amounts greater than 250 mg/l.

Beaver Creek strip-mined area restudied

The hydrologic environment of two small subbasins in southern Kentucky was studied during the period 1955–59 (J. J. Musser, 1963; C. R. Collier, Jr., and others, 1964; C. R. Collier, Jr., R. J. Pickering, and J. J. Musser, 1970). Parts of one of the subbasins, Cane Branch, had been strip mined intermittently from 1955 to 1959. There was no mining in the other subbasin, Helton Branch. The project was reactivated for the 1974 water year. Many of the parameters, such as streamflow characteristics and transported chemical and sediment loads, that had been measured in the original study were remeasured. According to J. A. McCabe, preliminary results showed that differences still exist between the two subbasins but to a lesser degree than in the earlier study, this fact indicating that there has been some natural restoration of the strip-mined subbasin.

Water quality in the Kentucky River basin, eastern Kentucky

The upper part of the Kentucky River drains a large part of the very actively mined eastern Kentucky coalfield. Results of a study by R. W. Davis showed that the predominant type of water in streams in the coal-mining area is not acid; however, acid drainage from mines is present. The water is generally alkaline (pH greater than 7), and about half of its dissolved-solids content is sulfate. The sulfate in the water is probably a product of the oxidation of iron sulfide minerals associated with coal beds, and the alkalinity that more than neutralizes most acid mine drainage is thought to come from calcareous material within the Pennsylvanian rocks in the area.

NORTH CAROLINA

Flow model of the Chowan River Estuary

A deterministic flow model based on the continuity equation has been developed to provide estimates of daily flow past selected points on the Chowan River of northeastern North Carolina. Perhaps the single most important feature of the model, designed by C. C. Daniel III and programmed by F. E. Arteaga, is its ability to calculate changes in storage for the river and the lower portions of four major tributaries.

The Chowan River is an estuarine body of water extending from the confluence of the Blackwater and Nottoway Rivers near the North Carolina-Virginia line to the mouth of the Albemarle Sound near Edenton, N.C. Two other important tributaries are the Meherrin and Wiccacon Rivers, both of which enter from the west. The estuary is about 80 km long and has an open water surface of approximately 120 km^2. Determination of the change in storage that corresponds to a change in stage is complicated by the presence of extensive swamps that border much of the river and its tributaries. These swamps have a total surface area nearly equivalent to that of the open water surface, their surface elevations are generally less than 1.5 m above mean sea level, and they are subject to frequent flooding. Lunar-tide variation in the river is only about 0.3 m, but wind tides are much more significant and cause as much as 1.2 m of variation in the water surface at irregular time intervals.

In order to determine the area of swamp subject to flooding and thus make an estimate of the volume of water that can be stored, maps have been drawn by using changes in vegetation as the criteria for topographic changes. Cypress and tupelo gum trees cover low areas subject to frequent flooding and tidal inundation, whereas pine trees grow on the higher, drier elevations within the swamp. Maps showing areas of differing vegetation were drawn on photomosaics at a scale of 1:62,500; delineation of vegetation types was facilitated by the use of LANDSAT (formerly ERTS) photographs taken in the red and near-infrared spectral ranges. Data from these maps, together with bathymetric data for the river channel, were combined to formulate the stage and storage relationships that are used in the model.

The model takes as input continuous hydrologic and meteorological data from numerous stations and converts these data into measurements of inflow, outflow, and changes in storage for selected segments of the estuary. The model then solves the continuity equation to provide estimates of flow through the estuary.

Ground-water resources of Wilson County

The most significant sources of ground water for Wilson County are (1) the sand beds of the Cretaceous aquifer system in the Coastal Plain section of the county, where maximum sustained yields of individual wells are estimated to be about 16 to 19 l/s, and (2) the bedrock aquifer system of the Piedmont section, where the maximum sustained yield is estimated to be about 7.9 l/s in stream valleys having perennial streams as sources of recharge.

A general decline of the water level associated with the Cretaceous System is centered around the Saratoga-Stantonsburg area, where the decline rate has averaged nearly 0.45 m/yr between 1942 and 1974. M. D. Winner, Jr., estimated that there is about 15 to 18 m of drawdown available before water levels will decline to the top of the uppermost sand beds of the system and dewatering could occur around a pumping well.

Distance-drawdown curves for a water-table aquifer

T. M. Robison used a digital computer to generate distance-drawdown curves for an idealized Coastal Plain water-table aquifer. The radial form of Darcy's law was used to compute the head differences across concentric cylindrical rings at increasing distances from a hypothetical pumping well. The inputs to the system were captured evapotranspiration and intercepted base flow. These inputs varied with drawdown and were computed for the top area of each cylindrical ring. The answers for each ring were determined by iteration.

PUERTO RICO

Alluvial aquifer and stream potential in Maunabo Valley

In the Río Maunabo valley in southeastern Puerto Rico, water from present wells will continue to meet municipal and agricultural needs if the wells are not overpumped. However, if the valley is to undergo considerable industrial development, water needs will have to be supplemented by surface-water control structures in the upper reaches of the Río Maunabo and by moderate-capacity wells in the upper part of the alluvial valley, according to D. G. Adolphson, M. A. Seijo, and T. M. Robison. Storage and control structures would aid in storing water from peak runoff periods for distribution when it is needed and in controlling floods.

In order to retain the maximum potential for ground-water resources in the upper part of the alluvial valley, additional wells could be located along the river. A digital model of the alluvial aquifer and data from test holes and existing wells indicate that the safe yield to the proposed wells would be about 13 to 32 l/s. Pumping rates in this range would insure that there would be no further encroachment of saltwater into the aquifer.

SOUTH CAROLINA

Flow and water-quality models of the lower Santee River

S. J. Playton collected data to calibrate J. P. Bennett's many-branched estuarine flow model. In addi-

tion, water-quality data were collected to attempt calibration of auxiliary transport models for substances such as sediment (for scour and degradation computations), BOD, and DO. These models will depict existing conditions and will predict discharge and water quality in the lower Santee River, in terms of temporal and spatial distribution, after a weekly average of 360 m^3/s have been rediverted from the Cooper River into a channel that now routinely carries 14 m^3/s. Water-quality data collected to date indicate that, with minor exceptions, water in the lower Santee River is of excellent quality.

Ground-water resources of southernmost South Carolina

A study of the ground-water resources of Beaufort, Colleton, Hampton, and Jasper Counties ("low country") was conducted by L. R. Hayes. Preliminary data from more than 300 wells and test holes indicate that most of the ground water in the study area comes from a limestone artesian aquifer composed of several Tertiary formations ranging in age from middle Eocene to early Miocene and from a deep artesian aquifer composed of sand of Late Cretaceous age. The limestone aquifer underlies Florida, southeastern Georgia, and adjacent parts of Alabama and South Carolina and is one of the most productive aquifer systems in the United States. In the northern and northwestern parts of the study area, the deep artesian sand aquifer will yield large quantities of soft good-quality water. However, in places, water from this aquifer has a high temperature and contains excessive amounts of fluoride.

High-fluoride-content ground water along the Grand Strand

According to A. L. Zack, there may be a relationship between the ionic fluoride (as much as 5 mg/l) occurring in ground water along the Grand Strand of Horry and Georgetown Counties and the occurrence of thin, limy, rock layers interbedded within the water-producing zone. Thin sections of the limestone indicate the presence of the mineral collophane, a massive apatite ($Ca_5(PO_4)_3F$). If aquifers with such rock layers are bypassed during well construction, high-fluoride-content ground water can be avoided.

TENNESSEE

Linear features provide clue to ground-water supplies

Linear features proved to be hydrologically significant in the search for ground-water supplies in the Manchester area, according to D. R. Rima. The Manchester area is situated on the eastern Highland Rim of central Tennessee and is underlain by relatively flat-lying carbonate and siliceous rocks of Early Mississippian age. The uppermost 10 to 20 m of these rocks are deeply weathered and form a thick zone of residuum.

Linear features that were apparent on aerial photographs were drawn on topographic maps. After field examination, sites were selected for test drilling. Eleven of 14 test wells drilled on linear features in the area had yields ranging from 12.6 to 25.2 l/s. Specific yields of the 11 wells ranged from 2 to 4 l s^{-1} m^{-1} of drawdown. These values are 4 to 10 times greater than the median values recorded for about 200 wells that were drilled in the area between 1963 and 1974.

Gains and losses in streamflow related to geologic structure in karst area

D. R. Rima reported that, in the karst area of Murfreesboro, a relationship has been established between geologic structure and gaining and losing reaches of streams. Gaining reaches usually occur downstream from the axes of synclines and upstream from the axes of anticlines. Conversely, losing reaches usually occur upstream from the axes of synclines and downstream from the axes of anticlines. In the Murfreesboro area, most of the gain or loss in streamflow occurs where streams cross the outcrop area of the bottom of the Ridley Limestone, which appears to be the most vulnerable to solution by circulating ground water.

Highland Rim-Central Basin aquifer

The Manchester aquifer occurs in the Highland Rim portion of the upper Duck River basin. This areally extensive artesian aquifer is the result of the weathering of cherty limestones of Mississippian age. It is composed of a chert rubble layer 6 m thick or solution openings in the bedrock. It is bounded on the top by 18 m of clay-sized chert and at the bottom by the Chattanooga Shale. Some wells in the aquifer yield 25 l/s, with specific capacities of 3 l s^{-1} m^{-1} of drawdown.

Relatively pure, dense Ordovician limestone in the Central Basin weathers and leaves a clay soil about 1 m thick. Solution openings along bedding planes and joints have developed, and secondary porosity has thus been created. The limestone is limited, however, in its ability to develop an areally extensive aquifer because of the discontinuous nature of solution openings and because of a 1.2-m-thick layer of bentonite 9 to 30 m below the land surface.

The bentonite is a barrier to the downward movement of water and the upward movement of natural

gas. Significant solution openings do not develop below it. According to C. R. Burchett (C. R. Burchett and E. F. Hollyday, 1974), only one of 15 test wells drilled in the Central Basin yielded more than 6.3 l/s. The average yield was 0.8 l/s, and six of the holes were dry. All of the water-producing zones in the 15 test wells were at depths of less than 30 m below land surface, and most were between 6 and 15 m below land surface.

CENTRAL REGION

Hydrologic activities in the central region during the past year continued, with strong emphasis on studies related to energy development, the environment, and other water problems of national importance as well as collection and timely publication of regional water-resource data.

Water-resource investigation programs related to coal and oil-shale mining and processing continued and made substantial progress during the year. Design and implementation of a network to define environmental baseline conditions were modified to provide for the special interests of other agencies that have management development or regulatory responsibilities in the field of energy development. Of special significance to coal development was the initiation of the plan of study for quantitative investigation of the Madison Limestone system underlying parts of Montana, North Dakota, South Dakota, and Wyoming. Several reports describing the impact on the hydrologic system of surface mining and reclamation in Colorado, Montana, Wyoming, and Utah were completed. Another major effort was the preparation of environmental impact statements for coal areas in Colorado, Montana, and Wyoming and a potash area in New Mexico.

Investigations of the Edwards Limestone aquifer in the vicinity of San Antonio, Tex., including deep test-well drilling and lithologic and geophysical studies, were begun. The investigations are expected to provide data leading to the development of methods for accurate measurements of hydrogeologic parameters that are needed for optimal development of the aquifer.

In the Houston, Tex., area, investigations of the increasingly serious land-surface subsidence resulting from industrial and municipal ground-water pumpage continued. Digital models for hydrologic studies were developed and used extensively. For example, in Colorado, the digital model of the aquifer system in the San Luis Valley was used to evaluate the operation of the present water-salvage project to reduce evapotranspiration from nonbeneficial vegetation. The digital model of the stream-aquifer system in the Arkansas River valley of eastern Colorado was used to evaluate the impact of diverting canal water to establish and maintain a permanent pool in the John Martin Reservoir. A digital model was developed and used to determine the impact of oil-shale development on the hydrology of the Piceance basin. Snowmelt models are being developed to determine the snowmelt streamflows from snow-packed areas on Pikes Peak. A digital model of the Platte River basin in Nebraska was prepared to determine the effects of irrigation on the stream-aquifer system.

Surface-water activities again were an important part of the regional program. Many gaging stations were installed in Colorado, Montana, Utah, and Wyoming to monitor the quantity and quality of stream discharge in the coal and oil-shale areas of those States. District offices throughout the region made substantial progress in mapping flood-prone areas, and type-15 flood-inundation studies of specific cities were made in several States. Flood-frequency studies were completed in Iowa, Kansas, Missouri, Oklahoma, and South Dakota; studies are in progress in Montana, Nebraska, North Dakota, Texas, and Wyoming. Urban hydrology studies underway in several metropolitan areas will define changes in runoff, water quality, and flood peaks of streams.

Studies of the effects of waste disposal and contamination on water quality of streams and aquifers are being made throughout the central region. Waste-assimilation studies in Arkansas have provided water-quality data for many Arkansas streams. Maps have been prepared showing location and quality of water in lakes in the Front Range urban corridor extending from Fort Collins to Colorado Springs, Colo. USGS scientists, in cooperation with Canadian scientists, are studying the quality of water and the biology of Lake Koocanusa and the Kootenai River, in northwestern Montana and northern Idaho, to determine nutrient levels and chemical quality in a stream and reservoir common to the United States and Canada. In the Platte River valley of central Nebraska, studies of nitrates in ground water are underway to determine the level and sources of contamination resulting from application of commercial fertilizers to agricultural lands and other possible point sources of contamination such as sewage lagoons and feedlots.

Hydrologic research in the central region included many activities related to energy development, such

as hydrochemistry of water from surface coal mines in Campbell County, Wyo., hydrologic impacts of surface mining on ground-water aquifers and the quality of water, and studies of changes in the organic quality of water with energy-related development. Other investigations are related to the chemical quality of water; they include a study of the salinity control in the Colorado River, development of modeling techniques for the prediction of solute transport in ground water, and development and calibration of a sediment transport model.

Research on the hydrology of geothermal systems is being conducted by field investigations and by the design and testing of downhole probes. Instruments have been designed and are now being tested under the extreme pressure and heat of geothermal wells. An instrument truck that carries 4,875 m of four-conductor cable for handling these probes was placed in operation during the year. Field studies of geothermal areas are underway in Colorado and New Mexico and are being planned to start early in fiscal year 1976 in Montana and Utah. Grant arrangements are in effect with two State agencies in Colorado for examining known geothermal resource areas and for a general Statewide reconnaissance.

ARKANSAS

Recharge to Cache River alluvial aquifer

M. E. Broom reported that, in 1973, recharge to the alluvial aquifer in the heavily pumped rice-growing area between the Cache River and Crowleys Ridge in eastern Arkansas was about 0.185 km^3. The principal area of recharge, underlain by relic dunes and dissected by perennial streams, is bounded by the White River and the Ozark Plateau escarpment on the west and by the Cache River on the east.

Pumpage from the aquifer in 1973 was about 0.493 km^3. A comparison of the recharge with the pumpage indicates that about 60 percent of the pumpage is in excess of annual recharge. Pumpage in excess of recharge is reflected by the water table, which declines locally about 0.3 m/yr.

Waste-assimilation studies incorporate low-flow frequency data

M. S. Hines reported that the comparison of flow-duration data and low-flow frequency data for 107 regular gaging stations in Arkansas reveals that, for all practical purposes, the 99-percent duration value is equal in magnitude to the 7-d 10-yr low flow. The 7-d 10-yr low-flow data that have been used for stream waste-assimilation studies indicate that the 7-d 10-yr low flow probably will be exceeded 99 percent of the time.

COLORADO

Drainage problem near Pueblo

Seepage from surface reservoirs and recharge from irrigation maintain the water table at or near land surface in an alluvial aquifer near Lake Minnequa in south-central Colorado, according to D. L. Bingham and P. J. Emmons. The aquifer ranges in thickness from about 0 to 7 m and is composed primarily of silt and fine sand. Because of the high water table, the area is marshy and the soil is waterlogged. Possible solutions to the waterlogging problem include construction of a cutoff trench or a drain-tile system to improve drainage and lower the water table.

Selenium in ground water from the San Jose Formation

During ground-water resource studies of the Southern Ute Indian Reservation, E. R. Hampton found that selenium in amounts exceeding USPHS drinking-water standards (10 $\mu g/l$) occurs commonly in water from the San Jose Formation of Eocene age. Forty-one samples from the San Jose were analyzed for selenium concentrations. Four samples contained selenium concentrations of 700, 450, 240, and 110 $\mu g/l$; 26 other samples contained smaller selenium concentrations that exceeded the USPHS limit for selenium in drinking water. Most of the water was obtained from domestic or stock wells that tap fractured varicolored shales interbedded with massive, poorly permeable sandstone.

Water from the underlying Animas Formation of Cretaceous and Paleocene age contained selenium concentrations of 45 $\mu g/l$ in 4 of 33 analyzed water samples from wells that tap the Animas.

Water-level declines projected for western Yuma County

W. E. Hofstra (W. E. Hofstra and T. J. Major, 1974) used a digital model of the ground-water system in a 2,000-km^2 area in western Yuma County to predict water-level declines as of the year 2000. Results of the study indicate that the maximum decline of the water table will be centered near the town of Yuma, where the saturated thickness (about 50 to 100 m) is greatest. A projected 15- to 26-m decline will occur in an area with from 30 to 76 m of water saturation in the Ogallala aquifer.

Quality of ground water in Jefferson County

The quality of the water in a mountainous area of Jefferson County is generally good, according to

W. E. Hofstra and D. C. Hall. The average dissolved-solids concentration in surface water is about 110 mg/l. The dissolved-solids concentrations in ground water are about 230 mg/l in water from the fractured Precambrian aquifer and 180 mg/l in water from the alluvial aquifer. Bacterial contamination is more frequent in water from the alluvial aquifer than in water from the Precambrian aquifer; coliform bacteria contamination was found in 35 percent of the samples from the alluvial aquifer and in 14 percent of the samples from the Precambrian aquifer. Fecal coliform contamination was found in 4 percent of the samples from the alluvial aquifer and 2 percent of the samples from the Precambrian aquifer. Chemical degradation of well water by leach-field leachate did not decrease significantly (95-percent confidence level) until distances from wells to leach fields were greater than 65 m.

Investigations in a coal-mining area

A geologic investigation and a surface-water reconnaissance of a coal-mining area were made by W. E. Hofstra and E. C. Linden. The study, which included determination of the dissolved-solids concentrations of streams and springs, was made during August 1974 in the coal-producing Yampa Valley and Danforth Hills area. Dissolved-solids concentrations in streams originating in the Williams Fork, Iles, and Mancos Formations commonly ranged from 550 to 700 mg/l. The trace-metal content of streams was greatest during spring peak flows, and the dissolved-solids concentration was greatest during the fall and winter base-flow period. Bicarbonate was the predominant anion during peak flow, and sulfate was the predominant anion during low flow. Magnesium content increased much more than calcium content during the base-flow period.

Water-quality variations noted in Park County

Ground-water quality is an important part of a water-resource study of Park and Teller Counties. According to J. M. Klein and K. E. Goddard, the Idaho Springs Formation of Precambrian age in northeastern Park County contains ground water that has more than 200 mg/l of dissolved solids, whereas the Pikes Peak Granite of younger Precambrian age contains ground water that has less than 100 mg/l of dissolved solids.

Salt Works Ranch Spring, which originates in the Maroon Formation of Pennsylvanian and Permian age in southwestern Park County, yields water that has a dissolved-solids concentration of 28,200 mg/l, a chloride concentration of 15,000 mg/l, and a sodium concentration of 9,400 mg/l. Salt Works Ranch is in an area of numerous sinkholes that result from local dissolution and caving of evaporite beds.

Appraisal of water resources of southwestern El Paso County

R. K. Livingston, J. M. Klein, and D. L. Bingham recently completed a water-resource study of southwestern El Paso County, where the annual water supply consists of precipitation, surface-water inflow, and imported water. A large part of the supply (71 percent) is estimated to be consumed by evapotranspiration. Mean annual precipitation ranges from 25 to 64 cm and is a function of altitude; fluctuations in annual and monthly precipitation are extreme. The chemical quality of surface water is generally good except for local high-fluoride concentrations that exceed USPHS recommended standards for drinking water. The addition of sewage effluent to lower Fountain Creek deteriorates the water quality.

Ground water occurs in the Widefield aquifer, in the alluvium in Fountain and Jimmy Camp Valleys, and in several bedrock aquifers. A mathematical model was prepared for the Dawson aquifer to simulate the effects of future withdrawals on the potentiometric surface and on hydraulically connected systems. Gain-and-loss investigations indicated that Fountain Creek is the primary source of recharge for the Widefield aquifer. The Widefield aquifer is the principal source of water for domestic use in southwestern El Paso County. The chemical quality of ground water generally is good.

Artificial-recharge experiments in Fountain Valley

Artificial-recharge experiments were conducted in five pits excavated in the unsaturated zone above the alluvial aquifer in Fountain Valley, according to O. J. Taylor. The artificial-recharge rates ranged from 0.03 to 1.37 m/d and varied with stage in the pits. The five pits, which have a total surface area of 4,650 m^2, are capable of artificially recharging at least 450,000 m^3/yr to the alluvial aquifer. Artificial-recharge operations can contribute to better water management in Fountain Valley by reducing shortages in water supply and improving water quality.

Electric-analog analysis of proposed changes in irrigation methods in the San Luis Valley

O. J. Taylor used an electric-analog model of the San Luis Valley to simulate the effects of proposed changes in irrigation practices. The reduction of surface- and ground-water irrigation in an area southwest of Alamosa will cause a decrease in stor-

age in the unconfined aquifer and an increase in storage in the confined aquifer. Additional effects of the changes will be an increase in the flow of the Rio Grande and Conejos Rivers and a decrease in the flow of the Alamosa River. Conversion to sprinkler irrigation throughout the valley will increase streamflow and storage in both aquifers. However, the predicted rise in the water table will result in a large increase in evapotranspiration.

Hydrologic evaluation of mine sites

Possible sites for an oil-shale mine in the Piceance Creek basin were studied by J. B. Weeks and G. H. Leavesley. The proposed mine will consist of a vertical shaft sunk through water-saturated sediments to the high-grade oil-shale deposits in the base of the Parachute Creek Member of the Green River Formation. Four sites, selected on the basis of their geologic and mineral resources, are being evaluated to determine which site will minimize the impact of the mine on the water resources of the Piceance Creek basin.

A digital model of the ground-water system is being used to estimate mine-shaft-dewatering rates for each site. Preliminary results indicate that construction of the mine shaft at a site on Ryan Gulch, a tributary of Piceance Creek, will produce the smallest amount of ground-water discharge and the lowest concentration of dissolved solids. Ground-water discharge during construction of the mine shaft may be as much as 0.57 m^3/s, and the concentration of dissolved solids may be 5,000 to 10,000 mg/l.

Hydrology of oil-shale lands

The hydrology of the Piceance and Yellow Creeks drainage basin, an area of about 2,330 km^2 in northwestern Colorado, was investigated by J. B. Weeks, G. H. Leavesley, F. A. Welder, and G. J. Saulnier, Jr. (1974), in cooperation with the Colorado Department of Natural Resources. The annual volume of runoff from the basin is estimated to be 19.2 hm^3. About 80 percent of the annual runoff is supplied by ground-water discharge.

Runoff from the basin is affected by irrigation diversions and by consumptive use by crops, native vegetation, and evaporation. Streamflow depletions resulting from irrigation are estimated to be 5.9 hm^3/yr. If there were no irrigation, the mean runoff from the basin would be 25.2 hm^3/yr. The period of lowest flow normally occurs during spring and summer when irrigation diversions are greatest. However, peak flows from snowmelt and thunderstorms occur during this period. A regional analysis, made by using the index-flood method, estimated flood frequencies in the absence of irrigation diversions. The estimated mean annual flood rates are 22.7 m^3/s for Piceance Creek and 11.0 m^3/s for Yellow Creek. The peak flow observed during the 5 yr of record on Piceance Creek was 11.5 m^3/s, or about one-half the estimated mean annual flood rate. Yellow Creek is only slightly affected by irrigation diversions, and the peak flow for the single year of record was 13.3 m^3/s.

Irrigation return flows and ground-water discharge affect the quality of surface water in the Piceance basin. The concentration of dissolved solids ranges from less than 500 mg/l in the upper reaches to more than 5,000 mg/l in the lower reaches of Piceance Creek and from about 700 to 3,000 mg/l in Yellow Creek. Water quality deteriorates in the downstream direction owing to ground-water discharge from the Green River and Uinta Formations.

The ground-water system in the basin consists of two principal aquifers separated by the Mahogany zone in the Green River Formation. Recharge to the aquifers occurs mainly from snowmelt along the basin margins above an altitude of 2,130 m. Ground water flows from the margins toward the north-central part of the basin, where it is discharged in Piceance and Yellow Creek valleys as evapotranspiration and streamflow. Recharge and discharge from the aquifer system are estimated to average 32.3 hm^3 annually. About 80 percent of the recharge is discharged in Piceance Creek drainage. Estimates of the volume of water in storage in the aquifers range from 3,100 to 31,000 hm^3.

Sodium minerals in the aquifer below the Mahogany zone are actively being dissolved by ground water. The Mahogany zone impedes the flow of water between the aquifers, and large chemical differences have developed. Water in the upper aquifer generally contains less than 2,000 mg/l dissolved solids, whereas the water in the lower aquifer exceeds 30,000 mg/l dissolved solids in the northern part of the basin.

Digital models were used to simulate the hydrologic system. A watershed model was adapted to the drainage above the gage on Piceance Creek below Ryan Gulch to evaluate the possible effects of precipitation changes on the hydrologic system due to the introduction of atmospheric pollutants from oil-shale development or from cloud seeding. Each 10-percent change in precipitation was found to result in a 40-percent change in ground-water recharge.

The model study indicates that a 10-percent decrease in October-May precipitation results in a 30-percent decrease in mean annual runoff, whereas 10- and 20-percent increases in precipitation result in 40- and 85-percent increases, respectively, in mean annual runoff.

A digital model of the ground-water system was used to evaluate the effects of mine dewatering on the hydrologic system. Hypothetical mines in oil-shale lease tracts C-a and C-b were considered. Both mines were assumed to be in the Mahogany zone and to be 10.4 km^2 in area. Dewatering of the mines was assumed to occur simultaneously for a period of 30 yr. For the hypothetical dewatering scheme simulated, the model study indicates that the mine in tract C-a will not produce enough water to meet the demand for processing and disposal of oil shale, whereas the mine in tract C-b will produce water in excess of the demand. The concentration of dissolved solids in the water discharged from the mines may not exceed 5,000 mg/l for the hypothetical dewatering scheme considered.

Dewatering the hypothetical mines will affect ground-water discharge in the Yellow Creek drainage only slightly. However, the model indicates that, after 30 yr of dewatering, ground-water discharge would cease in a 16-km reach of Piceance Creek near tract C-b. The decrease in ground-water discharge in this reach could cause an increase in the concentration of dissolved solids in the downstream reach of Piceance Creek. After 30 yr of dewatering, the hydraulic head in the aquifers would be decreased in 75 percent of the basin area, and about 620 hm^3 of water would be removed from storage in the aquifers.

Large ground-water reservoirs discovered in Rocky Mountain National Park

According to F. A. Welder and R. A. McCullough, seismic traverses in valleys in the northwestern part of the Rocky Mountain National Park (about 260 km^2) indicate that Quaternary glacial and alluvial deposits are as much as 122 m thick and contain as much as 1,230 hm^3 of ground water. Ground water in the park is essentially a calcium and sodium bicarbonate type. Specific conductance of the ground water ranges from about 100 to 300 μmho/cm at 25°C; the specific conductance of surface water is usually less than 100 μmho/cm. Aquifer tests in four wells tapping Quaternary deposits indicated transmissivities of 2.5, 75, 290, and 440 m^2/d.

KANSAS

Recharge-discharge relation in the Great Bend Prairie

In an investigation of water resources in the Great Bend Prairie, S. W. Fader and L. E. Stullken found that natural recharge to the ground-water reservoir averages about 300 hm^3/yr in the 5,800-km^2 area. The recharge is equivalent to about 50 mm of water over the entire area. Withdrawals of ground water for irrigation in 1974 amounted to about 170 hm^3, which was applied to about 10 percent of the land in the Great Bend Prairie. The withdrawals exceed the recharge rate in the irrigated area, but water levels in wells generally recover between pumping seasons because total withdrawals do not yet exceed total recharge.

Availability of ground water in Ness County

Results of a reconnaissance study of the water resources of Ness County by E. D. Jenkins and M. E. Pabst showed that water for irrigation and municipal supplies in the county is obtained principally from wells in the Pawnee River and Wet Walnut Creek valleys. Fifteen municipal wells and 160 irrigation wells are located in alluvium in the stream valleys. Wells in the Pawnee River valley reportedly yield 6 to 76 l/s. Wells in the Wet Walnut Creek valley yield from 2 to 32 l/s.

The eastern edge of the Ogallala Formation, which is the principal aquifer in western Kansas, crosses Ness County. However, only 15 municipal or irrigation wells tap the formation because well yields from the Ogallala in Ness County are marginal (maximum of 13 l/s) for these uses.

An irrigation well that reportedly yields 82 l/s and several domestic and stock wells tap the Dakota Formation, which underlies Ness County. Water from these wells generally is unsuitable for irrigation because it contains high concentrations of sodium.

Ground-water withdrawals for irrigation cause water-level declines in west-central Kansas

The rate of water-level decline is increasing in west-central Kansas, according to M. E. Pabst and E. D. Jenkins (1974). From 1950 to 1966, the average rate of decline was 0.2 m/yr. Records from 1966 to 1974, however, show that the average rate has increased to 0.4 m/yr. The increased rate of decline is attributed primarily to the effect on water levels of the rapidly expanding development of ground water for irrigation. Annual withdrawals of ground water for irrigation in west-central Kansas have increased from about 50 hm^3 in 1950 to 560 hm^3 in 1973.

Planning for prevention of water shortages during droughts in eastern Kansas

Results of a study of public water supplies in 43 counties in eastern Kansas showed that water-supply improvements are needed in many towns and rural water districts to prevent shortages in future droughts. H. G. O'Connor (Kansas Geological Survey) found that many of the smaller towns and districts do not maintain basic records of static and pumping water levels in wells or of changes in well yields as water levels decline during droughts. A program for preventing shortages has been proposed that includes (1) test drilling and water sampling to determine the quantity and quality of ground water available and to guide planning and development as water needs increase, (2) regular measurements of water levels and well yields to determine the performance of wells and aquifers, and (3) periodic evaluation of the records to anticipate impending shortages.

Statistical techniques used to estimate ground-water withdrawals in the Great Bend Prairie, south-central Kansas

Because accurate information on annual ground-water withdrawals needed by State and local planning and management agencies in Kansas is unavailable, various methods of estimating withdrawals are being investigated. For the Great Bend Prairie, L. E. Stullken and S. W. Fader obtained promising results by using statistical analyses of data from 32 wells randomly selected from a total of 1,160 irrigation wells in an area of 14,000 km^2. On the basis of repeated measurements of discharge from the sample wells, withdrawals for irrigation were estimated to be about 148 hm^3 in 1974. The statistical analyses indicate a 70-percent probability that the estimate is within 15 percent of the true value. The analyses also indicate that a 90-percent probability could be obtained for the same accuracy level if 100 wells were included in the sample.

Effects of pumping ground water from wells in the Dakota Formation in Ford and Hodgeman Counties

Between 9.5 and 18.5 hm^3 of ground water was pumped from irrigation wells in the Dakota Formation in Ford and Hodgeman Counties in 1973. Accordinng to E. C. Weakly (Kansas Geological Survey), the water, which was used to irrigate 3,120 hm^2, occurs primarily in sandstone lenses in the formation. Well yields and effects of pumping depend on the thickness, areal extent, cementation, and hydraulic connection of the sandstone lenses. The water is confined in some areas but unconfined in others. Water-level fluctuations differ greatly in response to the degree of confinement and quantity of water pumped. Water-level declines in wells in the counties ranged from 0 to 12 m during the period 1968–74.

LOUISIANA

New sources of fresh ground water discovered in St. James Parish

D. C. Dial reported that results of test drilling in St. James Parish along newly completed Interstate Highway 10 in a previously inaccessible backswamp area showed that water in the upper part of the regional Gonzales-New Orleans aquifer is suitable for public-supply use but that the lower part of the aquifer contains salty water. This fact is the first information on the southern limit of freshwater in the aquifer in St. James Parish.

New information for another site about 3 km northeast of Gramercy indicates that the Gramercy aquifer contains freshwater in an area where it was previously believed to contain slightly saline water. However, the areal extent of this zone of freshwater and the relations with the zone of slightly saline water have not yet been determined.

Quality of the Red River

Treated and raw municipal waste is discharged into the Red River at several locations between Shreveport and Moncla. Results of studies by D. E. Everett indicated that fecal coliform concentrations exceed 1,000 colonies per 100 ml most of the time and occasionally exceed 10,000 colonies per 100 ml. The highest concentrations generally occur downstream from Shreveport. On May 8, 1974, the fecal coliform concentration at Coushatta was 31,000 colonies per 100 ml.

New information on shallow aquifers in the Baton Rouge area

Recharge to the "400-ft" and "600-ft" sands, the principal aquifers in the Baton Rouge area, occurs mainly in an area of about 1,600 km^2 that is centered approximately 40 km north of Baton Rouge. Results of a study by A. J. Gogel indicated that water levels in the recharge area probably are not affected by heavy pumping in the Baton Rouge area; rather, water-level trends in the recharge area tend to reflect precipitation trends.

The initial pumping test of a large-capacity well in the recharge area indicated that the transmissivity is about 660 m^2/d, the hydraulic conductivity about 18 m/d, and the storage coefficient about 4×10^{-4}.

Ground-water quality in Lake Charles area

According to D. J. Nyman, two bodies of water in which the chloride concentration ranges from 50 to 440 mg/l have been defined in the "500-ft" sand of the Chicot aquifer in the Lake Charles industrial area of southwestern Louisiana. The bodies occur along the sides of a cone of depression resulting from industrial pumping about 10 km southwest of Lake Charles.

The source of the chloride in the water is apparently unrelated to industrial discharge; however, movement of saline water into the cone of depression is related to changes in the ground-water gradient as the cone of depression deepens. It is believed that the source of the saline water is isolated pockets contained in natural sedimentary traps at the bottom of the aquifer. The water in adjacent aquifers ("200-ft" sand and "700-ft" sand) and confining clays has a chloride concentration of less than 100 mg/l; the water in the aquifer between old oilfields to the northeast and the saltwater interface to the south generally has chloride concentrations of 20 to 50 mg/l.

Storage changes in the terrace aquifer in central and northern Louisiana

The increased ground-water storage in the terrace aquifer of central and northern Louisiana that resulted from above-normal rainfall during 1973 and 1974 could be beneficial to water users by increasing short-term supplies, according to T. H. Sanford, Jr. However, when long-term supplies are being planned, water users should take into account that storage varies with rainfall trends and decreases during periods of rainfall deficiency. Long-term water-level records indicate that as levels decline from high stages to levels typical of deficient rainfall periods, well yields may decrease as much as 25 to 35 percent.

Availability of ground water in the upland terrace aquifer, Bossier Parish

The terrace aquifer has not yet been used as a source of water for public-supply wells in most of the area of suburban development in southern Bossier and southwestern Webster Parishes. However, the Wilcox aquifer, the present source of public supplies, may not be able to meet all future demands. Analyses of water samples from test holes installed in the terrace aquifer during site studies by J. L. Snider indicated that in some localities the aquifer contains water with an iron concentration greater than 0.3 mg/l and a hardness greater than 180 mg/l but that in other localities the water has low concentrations of iron and hardness. The yields of two new public-supply wells in the terrace aquifer were 9.1 and 10 l/s. The sustained yield to continuously pumped wells in the terrace aquifer is estimated to be about 2.4 $l\ s^{-1}\ km^{-2}$.

Effect of Hurricane Carmen on water quality in Atchafalaya River basin

According to F. C. Wells, water quality in the southeastern part of the Atchafalaya River basin was affected by wind and rain associated with Hurricane Carmen, which passed just west of the basin on September 7 and 8, 1974. A deterioration in water quality was noted in an area south of Little Bayou Pigeon and east of the main channel of the Atchafalaya River.

On September 17, 1974, DO concentrations were less than 0.5 mg/l at five key stations in the backswamp area of the basin. The pH value of the water at the five stations was 6.6, sulfide concentrations ranged from 0.5 to 4.1 mg/l, and BOD concentrations ranged from 4.1 to 6.5 mg/l.

On October 11, 1974, a reconnaissance of the five key stations in the basin showed that concentrations of DO ranged from 0.5 to 3.3 mg/l, pH values ranged from 6.8 to 7.2, sulfide concentrations were less than 0.5 mg/l, and BOD concentrations ranged from 1.2 to 1.9 mg/l.

The degradation in quality on September 17 probably resulted from (1) a large amount of biodegradable organic matter from the bed material of the relatively shallow bayous that was put into suspension by wave action from Hurricane Carmen and (2) organic matter along the banks that was washed into the bayous by runoff created by the rainfall accompanying Carmen.

Water quality of the Red River alluvial aquifer

M. S. Whitfield, Jr., reported that chemical analyses of samples collected from 185 wells during 1974 indicate that the Red River alluvial aquifer normally yields water that is hard and has a very high concentration of iron. In 12 small areas, water in the alluvium contains excessive concentrations (>250 mg/l) of chloride and sulfate. The following table shows the general ranges and the extreme ranges of the more troublesome chemical constituents:

	Typical ranges (mg/l)		*Extreme ranges* (mg/l)	
	Low	*High*	*Low*	*High*
Hardness	300	600	28	1,100
Iron	3	10	0.05	40
Chloride	10	80	0.4	4,600
Sulfate	10	96	0	870

Only 11 of the wells sampled produced water that was either soft (<60 mg/l of hardness) or low in iron concentration (<0.3 mg/l), and only one well produced soft water with a low iron concentration. The water of better quality can be related to rapid infiltration or precipitation, lateral and vertical flow from adjacent units, or recharge from streams during high stream stage.

MONTANA

A hydrologic study of the Flathead Indian Reservation

Mission Valley, on the eastern side of the Flathead Indian Reservation, is underlain by Quaternary glacial deposits. The glacial deposits range from slightly permeable silt and clay (lakebed deposits) in the middle of the valley to permeable sand and gravel along the mountain front to the east. According to A. J. Boettcher, losses in streamflow result when streams flow from the Precambrian rocks of the Mission Range onto the coarse glacial deposits. The recharge water moves through the coarse deposits toward the middle of the valley where the aquifer is confined by the overlying lakebed deposits. Flowing wells have been developed from the coarse deposits in the Ronan area. Artesian springs are found in places where the lakebed deposits are thin or have been eroded away.

Ground water in the Libby area

An appraisal by A. J. Boettcher and K. R. Wilke of ground water in the Libby area of northwestern Montana indicated that the aquifer system (alluvial and glacial deposits of Quaternary age) could support increased ground-water withdrawal. An aquifer test indicated that transmissivity is about 370 m^2/d, and the well yield is more than 30 l/s.

Analyses of water samples from 91 wells show that the ground water is suitable for domestic supplies. However, some relatively high concentrations of nitrate (1.5 to 29 mg/l) in rural areas undergoing heavy residential growth indicate the presence of septic-tank effluent in ground water.

During an unseasonable flood in January 1974, maximum flows for most of the smaller streams equaled or exceeded a 50-yr flood, and water levels in wells along creeks rose markedly.

Ground-water study in a potential strip-mining area near Ashland

A study of the reclamation potential of strippable coal deposits in southeastern Montana was conducted by W. R. Hotchkiss on about three sections of coal-rich land between Threemile and Home Creeks, tributaries to Otter Creek near Ashland. The Knoblock coal unit, about 18 m thick, and 13 lesser coal seams of the Tongue River Member of the Fort Union Formation of Paleocene age are the major shallow aquifers in the area. Ground water flows west to southwest through the area and discharges to the bounding streams. The yield of water to wells from the Knoblock coal unit ranges from 0.2 to 0.3 l/s; specific capacity is about 0.02 $l\ s^{-1}\ m^{-1}$. Major constituents in water from the coal are sodium and bicarbonate or sodium and sulfate; the dissolved-solids concentration ranges from 1,210 to 4,090 mg/l.

A digital-computer model will be utilized to estimate the response of the local hydrologic framework to various stages and intensities of strip mining.

Flowing wells can be completed in Madison Group

W. R. Miller reported that flowing wells can be completed in the Madison Group in part of the Fort Union coal region south of the Yellowstone River. A preliminary potentiometric surface map, based on data from drill-stem tests, shows that water levels range from 90 m to more than 240 m above land surface along the Powder and Tongue Rivers. However, in the interstream areas, the potentiometric surface ranges from about 60 m to as much as 300 m below land surface.

Shallow aquifers above the Pierre Shale

Investigations looking into the hydrologic effects of strip mining of coal in southeastern Montana indicated that several aquifers exist above the Pierre Shale. According to R. S. Roberts, B. D. Lewis, and J. D. Stoner, the Fox Hills-basal Hell Creek aquifer overlies the Pierre and locally yields as much as 12 l/s of water to wells less than 300 m deep. The upper Hell Creek Formation may yield 3 l/s to wells generally less than about 240 m deep. Overlying the Hell Creek is the Fort Union Formation, which consists of three members. The upper unit, the Tongue River Member, contains discontinuous sandstone and coal beds that form the aquifer usually developed for domestic and stock supplies. Yields to wells are generally less than 3 l/s at depths less than 150 m. Alluvium along major valleys is reported to yield as much as 45 l/s to wells 18 m deep; however, most yields are less than 6 l/s.

NEBRASKA

Stream-aquifer models for basinwide resource planning, Platte River basin

The limits of the water-resource potential of the 105,700-km^2 Platte River basin were described by

means of digital models, according to E. G. Lappala. Because of the large size of the area and the detail desired, the basin was divided into five subbasins, each of which was modeled and integrated into the whole. Models used were finite-difference ground-water-flow models that incorporated features of base flow and evaporation salvage. Steady-state methods were used to calibrate four of the models by comparing computed recharge and discharge with historical precipitation and streamflow. The fifth model was calibrated by comparing transient water level changes. Net recharge or discharge for calibration and predictive analyses were computed by means of a model of monthly rainfall versus runoff and soil moisture. Water-resource development has been underway in the basin for nearly a century, first by stream diversion and later by ground-water withdrawal. At the present time, 3,240 km^2 is irrigated by stream diversions and 6,070 km^2 is irrigated by ground water, and it is projected that 16,000 km^2 will be irrigated by ground water by the year 2020. Results of the study are to be used in a comprehensive plan for water-resource management of the Platte River basin in Nebraska.

NEW MEXICO

Geothermal hydrology of the Jemez Mountains

According to F. W. Trainer, ground-water data for the southwestern part of the Jemez Mountains volcanic mass in north-central New Mexico suggest that much of the subsurface drainage from Valles caldera follows marginal faults at the western side of the Rio Grande rift zone. (The mountain mass stands astride the marginal fault zone.) Thermal springs and several cold springs and wells in San Diego Canyon, some of them near or associated with faults, yield waters believed to be mixtures of NaCl thermal water and shallow nonthermal ground water. The presence of thermal springs, together with observations in the canyon just outside the caldera rim—temperature observations in a well and the presence of a small fumarolic area—indicate active subsurface drainage of thermal water. This drainage contributes substantially to the chemical load of water in the Jemez River and in its alluvium by adding constituents, such as As, B, Cl, F, and Li, that are considered characteristic of volcanic water. In a few places, concentrations of the minor constituents have been found to exceed amounts established by the USPHS for potable water.

NORTH DAKOTA

Geohydrology of formations of Cretaceous and Tertiary age in Morton County

D. J. Ackerman investigated the availability and quality of water from aquifers in formations of Late Cretaceous and Tertiary age in Morton County. The aquifers are very fine to medium-grained sandstones that are interbedded with and grade into siltstones and silty shales. The formations dip to the northwest at a rate of about 2 m/km. Ground-water movement is generally eastward toward major discharge areas in the deep valleys of the Heart, Cannonball, and Missouri Rivers. The quality of water from these formations varies within individual aquifers and from one aquifer to another.

The hydrologic conditions within these formations are highly variable. However, a preliminary analysis of the collected data indicates that differences may be predictable.

Spiritwood aquifer extends into LaMoure County

C. A. Armstrong reported that test drilling in Dickey and LaMoure Counties has shown that the Spiritwood aquifer extends from the northern border of LaMoure County to the southeastern part of the county. The aquifer averages about 10 km in width through much of the county and generally ranges from about 10 to 40 m in thickness. Estimates of well yields, based on aquifer thickness and the grain size of the material in the aquifer, indicate that as much as 160 l/s can be obtained in some of the thicker parts of the aquifer. Yields of about 65 to 95 l/s should be obtainable from most of the central part of the aquifer. Analyses of two water samples show that the water is a very hard, sodium-bicarbonate type containing 732 and 911 mg/l of dissolved solids. Iron and manganese concentrations are high, and the sodium-adsorption ratios in the two analyses are 3.4 and 4.9.

Availability of ground water from lignite

R. L. Klausing reported that data collected during investigations of ground-water resources in Dunn County indicate that the majority of water wells drilled in the county are completed in lignite beds in the Sentinel Butte Member of the Fort Union Formation. The water-bearing lignite beds tapped by wells range in thickness from about 1 to 6 m. Yields from these wells, generally ranging from about 0.5 to 6 l/s, are adequate for stock and domestic purposes. Data from aquifer tests indicate that locally some of the lignite aquifers may yield from 1.9 to 6.3 l/s.

Short-term tests in two lignite aquifers gave transmissivities of about 70 and 1,800 m^2/d.

Extensive aquifer in Grant and Sioux Counties

P. G. Randich reported that test drilling in Grant and Sioux Counties has shown that the Fox Hills Sandstone is the most extensive aquifer in the two-county area. It crops out in the southeastern part of the area (Sioux County) and lies about 300 m below the land surface in the northwestern part (Grant County). Estimated potential yields to wells penetrating the aquifer range from about 0.2 to 10 l/s. Dissolved solids in 27 samples analyzed ranged from 296 to 2,020 mg/l and averaged 1,310 mg/l.

OKLAHOMA

Appraisal of ground water in the Garber-Wellington aquifer, central Oklahoma

Results of a study by J. E. Carr of the Garber-Wellington aquifer within the area between the Cimarron River and the North Canadian River indicated that there is a considerable quantity of water in storage. The aquifer supplies water for municipal, industrial, and domestic use. The maximum yield for deep wells is about 30 l/s, and the average yield is about 15 l/s. Yields from shallow wells are generally about 2 to 6 l/s.

The lower part of the aquifer contains brackish or saline water. The thickness of the freshwater interval (water with a dissolved-solids concentration of less than 1,000 mg/l) in the aquifer ranges from about 30 m north of Cottonwood Creek to about 240 m near Oklahoma City.

Well data in the outcrop area indicate that water generally is unconfined in the upper sands and that artesian conditions prevail in the deeper sands. Data show a water-level mound between Cottonwood Creek and Deep Fork. Ground water is discharged to most of the larger streams in the outcrop area.

Availability and quality of ground water in the Vamoosa aquifer

J. J. D'Lugosz reported that the Vamoosa aquifer underlies an area of about 6,480 km^2 in central Oklahoma and furnishes water for domestic and industrial uses and municipal supplies. However, the amount of water used is a small fraction of the total available.

Because of the variation in lithology, sorting, and grain size, porosity in the aquifer ranges from less than 10 percent to about 30 percent. Recovery tests show the aquifer to range in transmissivity from 28 to 46 m^2/d and the hydraulic conductivity to vary from 2 to less than 1.5 m/d.

Water in the upper part of the Vamoosa aquifer is fresh; dissolved-solids concentrations usually are less than 500 mg/l. The lower part of the aquifer, however, contains brackish or saline water. The zone containing water with a dissolved-solids concentration of less than 1,500 mg/l ranges from nearly 0 to about 220 m in thickness. In most of the area, water in the Vamoosa aquifer is a bicarbonate type containing less than 50 mg/l of sulfate or chloride. Locally, however, bromide-chloride ratios show that the aquifer has been invaded by saline water.

Investigations of ground-water supplies in the Antlers Sand, southeastern Oklahoma

Data compiled by D. L. Hart, Jr., showed that the Antlers Sand of Hill (1894) (Cretaceous) in southern Oklahoma has considerable quantities of water in storage. The areal extent of the aquifer is about 10,360 km^2, and thickness ranges from about 0 to 275 m. In about half the area, water in the aquifer is confined; in outcrop areas, however, the water is unconfined. The maximum measured well discharge is 41 l/s, but average well yields are about 15 l/s.

Recharge to the aquifer from precipitation occurs throughout most of the outcrop area. Discharge occurs primarily by ground-water losses to tributaries of the Red River, but some water is pumped from the aquifer for municipal and industrial uses. Additional quantities leave the area by downdip movement to Texas, and some water is discharged from flowing wells in the vicinity of the Red River.

The water in the outcrop area generally is a sodium-bicarbonate type containing less than 1,000 mg/l of dissolved solids. Locally along the Red River and in southeastern McCurtain County, the water is a sodium-chloride type containing more than 3,000 mg/l of dissolved solids.

SOUTH DAKOTA

Development of aquifers in north-central South Dakota

An estimated 8 million litres of water per day are withdrawn from glacial-outwash aquifers in Faulk, Edmunds, and McPherson Counties, an 8,500-km^2 area in north-central South Dakota. L. J. Hamilton reported that the pumpage, because it is evenly dispersed over the area and is only a small fraction of the annual recharge, has no large or lasting effects on water levels. Several aquifers in the area can supply wells yielding from 6 to as much as 60 l/s.

The very hard water from shallow glacial aquifers generally is of suitable quality for irrigation, since its sodium content averages less than 50 percent of the cations and its dissolved-solids concentration averages only about 800 mg/l. Water from deep glacial aquifers also is very hard but is unsuitable for irrigation because of a high sodium content (>50 percent of the cations) and a dissolved-solids concentration averaging about 1,300 mg/l.

Withdrawals of water from bedrock aquifers, mostly sandstone, are estimated to be 22 million litres per day. Since 1880, water levels have declined more than 76 m in wells in the Dakota Sandstone. Similar declines can be expected for the deeper high-pressure aquifers now being developed unless flows are carefully restricted. The water from the bedrock aquifers is not of suitable quality for irrigation use.

Test drilling in northeastern South Dakota

Aquifers in glacial-outwash deposits were penetrated by 25 of the 50 test holes drilled in 1974 in Clark County, a 2,500-km^2 area in northeastern South Dakota. According to L. J. Hamilton (USGS) and C. N. Christensen (South Dakota Geological Survey), the thickness of most of the outwash is less than 9 m. However, test holes in 5 widely spaced areas penetrated as much as 18 m of medium to coarse sand and gravel. The age of the outwash is considered to be younger than late Wisconsin because the outwash is overlain by up to 70 m of till. As much as 20 m of the till has been oxidized to a yellowish-brown color during a period of interglacial weathering.

Shallow glacial aquifer delineated in Hand County

A shallow glacial aquifer in northeastern Hand County has been delineated as a result of a test drilling program directed by N. C. Koch (USGS) and Ron Halgerson (South Dakota Geological Survey). The sand and gravel aquifer underlies an area of about 780 km^2, principally in the main drainageways of Medicine, Wolf, and Turtle Creeks. The sand and gravel bodies in these drainages are interconnected by a complex system of sand and gravel layers separated by gravelly clay. The sand and gravel, which occurs near the land surface, is about 5 to 27 m thick. The three creeks derive part of their flow from ground-water discharge from the aquifer. The aquifer can provide yields of about 10 to 32 l/s to wells. The water is very hard but is of generally suitable quality for irrigation use. The sodium content is less than 50 percent of the cations, and dissolved-solids concentrations are generally less than 2,000 mg/l.

Extensive basal-outwash aquifer in northeastern South Dakota

Test wells, which averaged 159 m in depth at 84 sites in Deuel and Hamlin Counties in northeastern South Dakota, revealed a buried basal-outwash aquifer that underlies a 1,750-km^2 area. Jack Kume reported that sand and gravel penetrated in drilling ranged in thickness from 1 to 31 m and was encountered at depths of 49 to 250 m. Its average thickness was about 11 m.

The aquifer was mapped as the lowermost outwash deposit in the thickest (268 m) glacial drift in South Dakota. It lies upon bedrock—Pierre Shale or Niobrara Formation (Upper Cretaceous)—or, in a few places, upon a thin layer of till adjacent to the bedrock.

TEXAS

Exploration for fresh ground water in basins of western Texas

J. S. Gates, D. E. White, and J. T. Smith drilled three deep test holes in the Salt Basin alluvial fill to determine its saturated thickness and water quality. The test hole drilled south of Valentine on Ryan Flat penetrated alluvium to about 120 m, thin volcanic flows and alluvium consisting mostly of reworked volcanic material to about 400 m, volcanic flows and tuff to about 460 m, and tuff to 610 m. Four water samples collected at depths between the water table (69 m) and 350 m were fresh.

The test hole drilled northeast of Van Horn on Wildhorse Flat penetrated alluvium to about 365 m and Cox Sandstone of Early Cretaceous age to 400 m. Water samples collected at depths between the water table (115 m) and 378 m, including a sample from the Cox Sandstone, were fresh.

The test hole drilled southwest of Van Horn on southeastern Eagle Flat penetrated alluvium that consisted mostly of clay and silt with thin beds of sand and gravel to 610 m. Water samples collected at depths between the water table (about 225 to 268 m) and 425 m were fresh.

Occurrence of porous evaporitic rocks in the Edwards Limestone

R. W. Maclay and T. A. Small reported that the results of studies of newly designated stratigraphic units of the Edwards Limestone in southern Texas indicate that some highly porous zones in the Edwards aquifer are associated with the evaporitic rock units previously identified by P. R. Rose (1972). Several cycles of marine to supratidal deposits occur within the middle third of the Edwards Limestone in the Bexar County area. A typical cycle originally consisted of a lower, pelleted mudstone unit, a mudstone

and wackestone unit containing algal mats and other tidal-flat structures, and an upper supratidal unit containing sucrosic dolomite and nodular gypsum or anhydrite. These supratidal deposits were exposed on extensive salt plains or "sebkhas" that were infrequently flooded by marine waters, which dissolved some of the nodular evaporites. The Kirschberg Evaporite Member (Rose, 1972) is one of the more laterally extensive units that can be identified from cores and geophysical logs. After burial and subsequent to faulting, meteoric water gained access to these rocks along fractures in the subsurface. These evaporitic units probably contribute much to the high transmissivity of the Edwards throughout Bexar and Comal Counties.

Digital-model study of ground-water hydrology in the El Paso area

A digital model of the hydrology of the Hueco Bolson near El Paso was constructed by W. R. Meyer to simulate historical water-level declines and to predict future water-level declines. The model indicates that additional water-level declines ranging from about 14 to 21 m can be expected in the area by the year 1991. The model also indicates that seepage losses from the Rio Grande will increase from about 14,800,000 m^3/yr to about 19,500,000 m^3/yr by 1991.

The model can be used as an aid in determining the optimum areal distribution of wells, and different pumping procedures can be simulated to assist in determining a pumping pattern that will result in more uniform drawdown in the area of production.

UTAH

High transmissivity in northern part of Parowan Valley

According to L. J. Bjorklund and C. T. Sumsion, an aquifer test in the northern part of Parowan Valley indicated that the water-bearing material has a high transmissivity.

Water-level measurements made in March 1974, before the pumping season, indicated that the potentiometric surface of the ground-water reservoir had an almost horizontal gradient—about 0.09 m/km. Water-level measurements made in October 1974 also indicated a flat potentiometric water-level surface, but it was about 0.6 m lower than the March surface because water was removed during the irrigation season.

An aquifer test in Buckhorn Flats indicated a transmissivity of about 18,600 m^2/d; almost uniform results were observed in nine observation wells in an area of about 3,240 hm^2. An irrigation well was pumped at rates between 190 and 250 l/s, and water-level observations were made in wells at radial distances ranging from 900 to 3,700 m. Drawdown of the water level in a well 900 m distant was observed within 10 min after pumping began and increased to 0.39 m during 16.4 d of pumping. The maximum drawdown in the pumped well was 6.1 m. The pumped well penetrated 125 m of unconsolidated material consisting of near-surface silt and clay underlain by silt, sand, gravel, cobbles, and boulders, mostly of volcanic origin.

WYOMING

Water losses from streams to the Madison Limestone

Thirty-two gaging stations were established on 17 streams in the fall of 1974 in northeastern Wyoming to collect streamflow data for use in determining potential recharge to the Madison Limestone aquifer. The outcrop areas are along the northern and northeastern flanks of the Laramie Mountains, the eastern slopes of the Bighorn Mountains, the western part of the Black Hills uplift, and the Hartville uplift near Jay Em. More than 50 stream channels were investigated during the geologic and hydrologic field reconnaissance. F. C. Boner reported that discharge measurements made during the fall of 1974 indicate that nearly all streams crossing the outcrop areas in the Laramie Mountains lost water to the aquifer. In the Bighorn Mountains, about 60 percent of the streams showed gains and the remainder showed losses; however, volumes of gains and losses have not yet been calculated. Streams in the western Black Hills uplift showed gains.

Geohydrology of the Albin and La Grange areas

In the Albin area, the Ogallala Formation was found to be saturated only in coarse-grained channel deposits from which most of the irrigation wells pump, according to W. B. Borchert. Water levels in parts of these channel deposits have declined about 1.2 to 2.1 m since pumping began in 1968. However, in the area southeast of Albin, about 1.2 m of the 2.1 m of decline can be attributed to a 170-percent increase in ground-water pumpage between 1973 and 1974.

In parts of the La Grange area, the net effect of ground-water pumpage and surface-water recharge since 1969 has resulted in a rise of about 1.2 m in water level. In two large-diameter wells drilled into the Brule Formation, secondary porosity was located by using caliper logs and acoustic borehole televiewer logs. Geophysical logs were run in these wells. At known depths of secondary porosity, the response of

the geophysical logs to secondary porosity in the Brule Formation was evaluated and a basis for future comparisons established.

Hydrologic analysis of the valley-fill aquifer, North Platte River valley, Goshen County

Water-level measurements taken in observation wells indicated that little change in storage occurred in the valley fill in Goshen County during a 1-yr period. M. A. Crist (1975) reported that annual recharge to ground water from precipitation, seepage from canals, and seepage from surface-water irrigation amounts to about 89.4×10^6 m^3 and is nearly equal to the 94.1×10^6 m^3 estimated as the ground-water contribution to the North Platte River. The valley fill is estimated to contain about 2.1×10^9 m^3 of water in storage. A digital model developed during the investigation can be used to predict the general effects of changes in stress that might be applied to the system.

Impacts of coal development on topography and shallow aquifer in Gillette area

R. F. Hadley and W. R. Keefer (1975) reported that results of studies in an area of about 2,500 km^2 in central Campbell County showed that the Wyodak-Anderson coal bed is less than 60 m below land surface in approximately 30,000 ha and less than 90 m below land surface in an additional 13,500 ha. Topographic cross sections have been prepared to show some of the broad-scale changes that can result from surface mining. For example, if a "swell" factor of 25 percent is assumed, the surface would be lowered about 19 m in those areas where the coal bed is 30 m thick beneath an average overburden of 46 m. Cross sections also show the inferred effect on the ground-water system of a hypothetical surface-mining operation. Water levels in wells tapping shallow aquifers may be substantially lowered within about 6 km of individual mining operations. Determining the longevity of the lowered ground-water levels and their possible recovery to premining levels will require monitoring of wells under actual mining conditions.

Hydrologic investigations related to fossil fuels

R. E. Hodges, Joe Sena, and L. M. MacCary began a research program on borehole geophysics as applied to coal-related studies. Coal deposits are easily identified on the density, neutron, and resistivity logs. In areas where the coal bed is the aquifer, geophysical logs will be used to estimate the effective porosity, and televiewer logs will be used to determine the type and orientation of the fractures. Logging of the Madison Limestone in Wyoming has been initiated in coal-related studies to determine the availability of ground water for coal-slurry operations and coal-fired steamplant operations. The Madison Limestone has been logged at depths of about 915 m, but it attains depths of 3,650 m in the deeper parts of the Powder River Basin. A newly acquired logging truck with a capacity of 4,875 m will be used for geophysical measurements in these areas.

Dye-recovery study in Tongue River Cave

The occurrence of subterranean stream diversion between two surface-drainage basins on the eastern flank of the Bighorn Mountains has been established by a quantitative dye-recovery study conducted in Tongue River Cave. This limestone cave, located in Tongue River Canyon, contains a free-surface stream having a low-flow discharge of 0.04 m^3/s.

D. T. Hoxie reported that 396 ml of Rhodamine-WT dye was introduced into the Little Tongue River near the point where it sinks into the Bighorn Dolomite of Ordovician age; 35 percent of the injected dye was eventually detected in the cave stream. The Little Tongue River is nominally tributary to the Tongue River; however, under conditions of normal and low flow, water in the main fork sinks into the streambed upon flowing onto the Bighorn Dolomite; this reach is located approximately 4 km south of the cave and is some 760 m higher in elevation. The sharply peaked dye-recovery curve suggested the presence of a single solution conduit linking the cave and the sink. The time required for the dye to travel from its injection point into the cave was approximately 24 h.

WESTERN REGION

Water-resource studies in the western region covered a wide range of topics, and both old and new instruments and techniques were used to accomplish objectives.

The increasing need for real-time data for (1) the daily operation of river systems for flood forecasting and warnings and (2) the determination of water-quality parameters has resulted in expanded programs in several States but primarily in the Columbia River basin. Radios, direct-line telemetry, and the transmission of data by satellite are among the techniques now in use at many sites.

The intensive water-quality assessment of the Willamette River basin in Oregon is a successful pilot

effort to define the basin's past and present quality and to develop mathematical models to project quality conditions under alternative plans for basin development. Results of this work will provide bases for similar assessments of other river basins across the Nation.

Ongoing programs include the following: (1) Quantification of geothermal resources at known geothermal areas, (2) San Francisco Bay region environment and resources planning study, (3) studies to define the areas inundated by 100- and 500-yr floods for flood-insurance purposes, and (4) collection and analyses of data for surface and ground water and water quality.

MULTISTATE STUDIES

Great Basin ground-water appraisal

As one of a number of summaries of the Nation's ground-water resources (Pacific Southwest Inter-Agency Committee, 1972), an appraisal was made of ground-water resources in the Great Basin by T. E. Eakin, Donald Price, and J. R. Harrill. They reported that ground-water withdrawals from wells in the Great Basin region were about 1.4 km^3 in 1970. The region could sustain an annual net pumpage of about 3.2 km^3. Larger withdrawals could be sustained if only part of the pumped water is used consumptively, if conflicts with existing surface-water rights are resolved, and if extensive treatment, artificial recharge, and reuse of water prove feasible. Ground water stored in the upper 30 m of the saturated deposits of the valley ground-water reservoirs is on the order of 370 km^3. Total ground-water storage exceeds several thousand cubic kilometres.

Similar appraisals have been started in the Lower Colorado River basin and in the Pacific Northwest, and an appraisal of the California region is nearing completion.

ALASKA

Channel erosion surveys

Channel surveys and low-altitude vertical aerial stereophotography at 24 sites along the trans-Alaska pipeline route in central Alaska were used to document topography before construction. Resurveys and photography were obtained after partial construction of a haul road and construction camps for the pipeline. J. M. Childers (1972) reported that gravel extraction from flood plains has removed large areas of flood-plain vegetation and formed deep and extensive floodway basins. The haul road constricts floodways and may concentrate floodflow to promote or accelerate channel erosion.

Gas-saturation studies at salmon-rearing sites

G. A. McCoy collected gas-saturation data at the following locations: Crystal Lake hatchery near Petersburg; Fire Lake hatchery near Eagle River; several streams in south-central Alaska; and at rearing pens at George Inlet near Ketchikan, Starrigavan near Sitka, and Halibut Cove Lagoon. The three rearing pens are in a gravel-bed stream, saltwater, and an estuary, respectively.

Data on saturation of nitrogen and DO have been obtained. Measurements for methane have been made, but none has been detected. Significant supersaturation of dissolved gases has been found only at the Crystal Lake hatchery.

Hydrologic and limnologic investigation of the Karluk River basin

G. A. McCoy and D. R. Scully collected streamflow, chemical, and physical data for streams and lakes in the Karluk River basin on Kodiak Island. Three stream-gaging and water-temperature recording stations have been established on tributaries to Karluk Lake. Chemical and physical data were collected on tributaries to Karluk Lake, Karluk Lake itself, Karluk Lake outlet, and Thumb Lake. Preliminary results indicate that water quality is good in this area. Karluk Lake is oligotrophic, and conductance of water in all streams is less than 100 μmho at 25°C.

Hydrologic reconnaissance of St. George Island

G. S. Anderson conducted a hydrologic reconnaissance to determine the potential for developing potable ground water on St. George Island. Existing wells, which produce saline water, are believed to be either too deep or too close to the ocean. The fresh ground-water lens is thought to be thin because the island is small, the rocks are permeable, and recharge is low. However, it should be possible to skim limited quantities of fresh ground water if new wells are drilled farther inland and reach the freshwater lens.

ARIZONA

Effects of vegetation change on water and sediment yield

Precipitation, streamflow, and sediment data were collected from two similar watersheds in the Sycamore Creek area to define changes that may take place in runoff and sediment yield if the dense native chaparral in one of the watersheds is replaced by grass. Each watershed occupies about 11.7 km^2, and their physiographies and climates are similar. Ac-

cording to H. W. Hjalmarson, analyses of streamflow and precipitation data indicate that any appreciable change in runoff owing to the replacement of native chaparral by grass can be determined quantitatively. Statistical analyses indicate that under optimum conditions an increase in runoff of as little as 19 percent may be evaluated at the 95-percent level of confidence. Because the natural variation in suspended-sediment yield is large, a change caused by a substitution of vegetation is difficult to assess.

Ground-water resources of southern Navajo County

According to L. J. Mann, the Coconino aquifer that underlies southern Navajo County furnishes about 46.9 hm^3 of water per year to wells. In addition, about 2.17 hm^3 of water is obtained from the Pinetop-Lakeside aquifer in the southeastern part of the county, and about 1.23 hm^3 is withdrawn from the alluvium along the channels and flood plains of the Little Colorado River and its major tributaries. In the southern part of the area, ground water generally contains less than 350 mg/l of dissolved solids—mainly calcium, magnesium, and bicarbonate. In the northern part, however, the water contains from 500 to as much as 68,200 mg/l of dissolved solids—mainly sodium and chloride.

The Coconino aquifer includes the Coconino Sandstone, the uppermost beds of the underlying Supai Formation, and the overlying Kaibab Limestone. Most of the water withdrawn from the aquifer is used for agricultural and industrial purposes. Several small cones of depression have formed near the large agricultural and industrial areas. Although water-level declines of as much as 15 m have been measured, declines generally are less than 1.5 m.

The Pinetop-Lakeside aquifer includes a bedded sequence of sedimentary rocks, rim gravel, and basaltic rocks. Ground water in the Pinetop-Lakeside aquifer and in the alluvium generally is hydraulically separated from that in the underlying Coconino aquifer. The Pinetop-Lakeside aquifer supplies water to resort areas near Pinetop and Lakeside. The alluvium may yield sufficient quantities of water for irrigation, but most wells that tap this unit furnish water for domestic and livestock uses.

Perched ground water in the northern part of the La Posa Plain

According to D. W. Wilkins, two known areas of perched ground water are present along Tyson Wash in the northern part of La Posa Plain—one area surrounds the town of Quartzsite and the other is about 13 km south of Quartzsite. The shallow ground water is perched on the Bouse(?) Formation. In the area surrounding Quartzsite, the depth to water ranges from about 8 m below the land surface near Tyson Wash to 39 m below land surface about 2 km east of the wash. In the area south of Quartzsite, the depth to water ranges from 34 to 46 m below the land surface. The perched ground water is recharged from flow in Tyson Wash. Two flow events in July and August of 1974 caused water-level rises of as much as 1.5 m in wells adjacent to the wash. The chemical quality of the perched ground water is good; dissolved-solids concentrations range from about 100 to 700 mg/l.

Geology and ground-water resources of the Sedona area

G. W. Levings identified the Verde Formation, the Supai Formation, and the Redwall Limestone as the major aquifers in the Sedona area. Although faults in the area do not seem to have a significant effect on ground-water movement, localized fractures, joints, and solution channels may significantly increase the secondary permeability of the formations and may be associated with the increase in well yields. A comparison of water levels measured in the late 1950's with those measured in the early 1970's shows that there has been no water-table decline. The water is of suitable chemical quality for domestic and municipal uses and for irrigation; the main constituents are calcium, magnesium, and bicarbonate.

CALIFORNIA

Madera area ground-water model

A digital-computer simulation model of the ground-water system in the Madera area of the east-central San Joaquin Valley was constructed by using immediately available data. The first attempts at model calibration quickly demonstrated that significant errors existed in available water-level and pumpage data. According to W. D. Nichols, a reevaluation of water-level data strongly sugggests that the major cause of poor calibration is pumpage data computed from power consumption. This conclusion requires a complete reevaluation and probably a recalculation of pumpage data for the area being modeled. The model results will assist in designing data-collection programs to obtain the more reliable data needed for calibration.

Ground water in Garner Valley

T. J. Durbin reported that Garner Valley is an intermontane alluvial basin in the San Jacinto Mountains. An alluvial aquifer with a surface area of 54

km^2 underlies the valley floor. A mathematical representation of the aquifer was used to compute average annual recharge and discharge.

The aquifer is in a state of equilibrium, and recharge from precipitation equals ground-water discharge to phreatophytes and to Lake Hemet, a reservoir in the northern part of the valley. The average annual recharge is 2.7 hm^3. The average annual discharge to phreatophytes is 1.4 hm^3, and the average annual discharge to other minor sources is 0.1 hm^3.

Water purveyors in an adjacent drainage basin are considering the annual export of 0.5 to 1.1 hm^3 of ground water from Garner Valley, which would cause an equal reduction of the natural ground-water discharge in the valley.

Rainfall-runoff data prepared for urban hydrology study in Poway region

According to J. A. Skrivan, rainfall data at five sites in the Poway Creek basin covering about 110 km^2 and streamflow data at the basin outlet have been collected since November 1969. All precipitation and streamflow data were obtained at 5-min intervals and have been punched on cards for use in a rainfall-runoff digital model. Photographs of the region are being taken annually to record land-use changes.

Urban runoff and erosion studies in Perris Valley

Since 1969, the effects of urbanization on the hydrologic regimen of the Perris Valley area have been studied. According to R. P. Williams, data collection emphasizes rainfall-runoff relations, sediment production, and general water quality.

Because rainfall was low during most of the project, few events are available for analysis. When runoff does occur, sediment concentrations are evaluated every 15 min at four sites. Suspended-sediment concentrations of 10,000 mg/l are common during storm events.

The results of the study will be used for land-use planning in other areas of Riverside County.

Isotope study of California ground-water recharge

Several California ground-water basins are being recharged with surface water imported from northern California. T. B. Coplen II, L. A. Eccles, and P. A. Emery investigated the feasibility of tracing the recharge water through the ground-water system by using stable isotopes of hydrogen (D/H) and oxygen (O^{18}/O^{16}). They have found that northern California water can be differentiated from "native" ground water in the vicinity of San Jose.

Nitrate in ground water, Redlands area

According to L. A. Eccles, agricultural development and urbanization in the Redlands area depend on multiple use and reuse of ground water. The recycling of water to the saturated zone has resulted in degradation of the water, especially by nitrate, mostly in the vicinity of agricultural operations and points of waste discharge. The most probable causes of nitrate accumulation in the ground water are previously high application rates of nitrogen on citrus crops, low soil-denitrification potential, and high infiltration rates, aggravated by recycling of ground water.

Since the advent in the 1960's of requirements for leaf analysis of nitrogen-fertilized citrus crops, the largest source of nitrate in ground water has been greatly reduced. Some citrus growers irrigating with water having a high-nitrate content have not applied nitrogen fertilizer for more than 5 yr. The projected high cost of nitrogen fertilizer will also serve to reduce this source, as will the trend toward urbanization.

The largest potential source of nitrate is the unsaturated zone. There is a considerable time lag between the application of nitrogen on the surface and its appearance at the water table. An experiment by other researchers on a soil solution taken below the root zone has shown that with a nitrogen-fertilization rate of 390 kg. hm^{-2}/yr^{-1} and a leaching fraction of 0.4, there was a nitrate concentration of 198 mg/l. If the water table were to remain static, the rate of nitrate migration might be low enough to prevent an increase of nitrate in the saturated zone, but an increase in the elevation of the water table would lead to higher nitrate concentrations beneath areas of previously high nitrogen application.

The most recent nitrate data for the area show a declining trend, although locally some wells produce water with nitrate concentrations in excess of 90 mg/l. This trend is expected to continue, although there may be periodic increases in nitrate concentrations in some wells.

Quality of ground water in western Sacramento Valley

Ground-water samples from 222 wells located on the western side of the Sacramento Valley were analyzed for mineral constituents. G. L. Bertoldi reported that results of the analyses show that the native ground water is of a calcium magnesium bicarbonate type with a dissolved-solids content of generally less than 300 mg/l. Two small areas of sodium-chloride-type water and four areas underlain by wa-

ter having boron concentrations in excess of 0.75 mg/l (the recommended maximum limit for boron-sensitive crops) were also found. With the exception of locally high boron concentrations, the water is suitable for irrigation of almost all types of crops and generally is of good quality for domestic use.

Storage capacity, ground-water discharge, and ground-water movement in the Fresno area

Estimates of storage capacity and ground-water discharge were made for an area of about 344 km^2 northeast of Fresno. According to R. W. Page, total storage capacity in the upper 61 m of the ground-water reservoir is about 1,357 hm^3, and ground-water discharge from the area is about 74 to 86 hm^3/yr. Water demands for urban use were larger in January 1975 than in January and February 1963, but the change in water use did not greatly affect the general direction of ground-water movement between 1963 and 1975.

Ground-water resources evaluated in the Ocotillo-Coyote Wells region

J. A. Skrivan reported that the principal source of recharge for the alluvial aquifer in the Ocotillo-Coyote Wells area is precipitation in the mountains to the west and southwest. The general ground-water movement is from these recharge areas eastward to the Salton Sea and southward to Mexico.

Wells in Ocotillo can produce 25 to 32 l/s of water with a dissolved-solids content of about 500 mg/l. However, just 8 km to the east, the dissolved-solids content of water from some wells is 18,000 to 24,000 mg/l. The Elsinore fault, which bisects the region in a southeasterly direction, probably is an effective ground-water barrier separating the high-quality ground water in the western part from the poor-quality water to the east.

Artificial-recharge feasibility in the upper Santa Ana River area

Results of a study of the feasibility of artificial recharge for the upper Santa Ana River area by D. H. Schaefer and J. W. Warner indicated that a maximum of 100 hm^3/yr could be recharged. Water from the State Water Project will be available in a few years for artificial recharge in this area.

The upper Santa Ana River area is well suited for artificial recharge because it is largely underlain by permeable river-channel deposits. Test drilling indicated some local sandy clay layers, but they were not extensive enough to impede recharge.

Ground-water hydrology in Round Valley

Preliminary results of studies by K. S. Muir indicated that there was no overall decline in water levels in Round Valley between 1951 and 1974. The quantity of ground water pumped from wells in 1974 did not exceed the yield of the basin, and the ground-water reservoir remained full. Potential recharge was rejected as streamflow.

The quality of the ground water was found to be excellent for irrigation and had not changed significantly since previous studies made in 1951.

Anza-Terwilliger geologic and hydrologic study

W. R. Moyle, Jr., completed a study in the Anza-Terwilliger area of Riverside County that included the Cahuilla Indian Reservation. The study deals with geology, steady and transient states of ground water, net depletion of ground water, chemistry of water, precipitation, and land and water use in the area. It also includes a complete Bouguer gravity map, geologic and hydrologic cross sections, and hydrographs. The data show that more water was consumed in 1973 within the study area than is being recharged by average annual precipitation and that water levels have declined locally as much as 23 m between 1950 and 1973.

Temecula gravity map

W. R. Moyle, Jr., and D. J. Downing (1975) prepared a complete Bouguer gravity map of the Temecula area in Riverside County in cooperation with the Joint Administration Committee of the Santa Margarita and San Luis Rey Watershed Planning Agencies to aid in the exploration for and development of ground-water supplies. The map shows the relative thickness of alluvial deposits that contain ground water and areas where the basement complex is near the surface.

HAWAII

Hydrology and sediment transport, Moanalua Valley

Five years of intensive data collection in Moanalua Valley resulted in some observations concerning the rainfall-runoff and rainfall-sedimentation characteristics of the 8.65-km^2 basin (B. L. Jones and C. J. Ewart, 1973). According to Ewart, average annual rainfall for the period 1969–73 ranges from 1,700 mm at the downstream boundary of the project to 4,040 mm near the headwater area. A water budget constructed for the upper half of the basin reveals that runoff, evapotranspiration, and ground-water recharge comprise 15, 25, and 60 percent of the annual

rainfall, respectively. Analyses of the suspended-sediment data collected from two locations in the valley indicate a good correlation between total sediment discharge during a storm and peak discharge. Observations indicate that the stream frequently transports very large boulders (in excess of 0.6 m in diameter).

Water resources of eastern coast of Kauai

Kauai County officials believe that municipal water supplies under drought conditions are not adequate to meet increasing demands for water resulting from urban expansion and resort development in the towns on the eastern coast of Kauai. Currently, the only source of domestic supply is ground water from wells and tunnels. R. J. Burt reported that most of the pumpage is from perched-water bodies in the generally poorly permeable lava flows of the Koloa Volcanic Series, the younger of the two major volcanic rock formations of the island. Recently drilled wells in the Koloa rocks have not provided the needed additional water.

The Koloa lava flows are thick and dense and overlie an undefined erosional surface of the older Napali Formation of the Waimea Canyon Volcanic Series. The Napali Formation rocks are generally highly fractured and permeable, but they are considered to be too deep near the towns for economical development of ground water. However, in a few locations, the Napali rocks protrude as steptoes or "islands" above the Koloa rocks. These areas have not yet been fully explored for ground water. A well in the protruding Napali rocks might be effective in draining water from the Koloa rocks because the "island" of permeable Napali rocks may act as a giant infiltration gallery. Water levels in both the Napali Formation and the Koloa Volcanic Series are high owing to the confining effect of the Koloa rocks.

Although the streams of Kauai have relatively uniform and high base flows in comparison with other streams in Hawaii, ground water has been preferred for domestic use because it is clear and does not require treatment.

IDAHO

Effects of pumpage on Thousand Springs

Ground-water withdrawals for irrigation in Gooding and Jerome Counties during 1973 were computed by J. A. Moreland. Pumpage, computed from power-company records, totaled about 105 hm³. A digital hydrologic model was constructed to simulate water-level fluctuations and spring discharges in the Snake River Plain aquifer. The model was successfully calibrated for 1966 conditions on the basis of inputs supplied by the Idaho Water Resources Research Institute. Several alternative water-use plans were simulated on the model to evaluate the effects of the plans on ground-water levels and spring discharges.

Water resources of Henrys Fork basin above Ashton

The USGS, in cooperation with the Idaho Department of Water Resources, is conducting a 2-yr water-resource investigation of the 2,764-km² Henrys Fork basin above Ashton.

R. L. Whitehead, W. A. Harenberg, and H. R. Seitz reported that monitoring networks for ground-water, surface-water, and quality-of-water data have been established to determine the chemical and physical characteristics of the basin's water resources. The basin is in a nearly primal state, but its abundant recreational features serve to attract an increasing number of people each year. It is therefore important to establish a data base from which effects of future recreational activities and developments can be evaluated.

Generally, analyses of samples from more than 60 selected sites within the basin indicate that the water is of excellent quality.

Water resources of the Weiser River basin

A 2-yr investigation of the water resources of the Weiser River basin was initiated by H. W. Young, W. A. Harenberg, and H. R. Seitz. The first year's effort consisted primarily of the establishment and operation of monitoring networks to assist in describing and characterizing the water resources in the basin. Included in this network are 22 surface-water measuring sites, 25 ground-water observation wells, 13 surface-water sediment sites, and 3 quality-of-surface-water sites.

An inventory of approximately 350 wells in the basin indicates that both artesian and water-table aquifers are present. Ground-water-level fluctuations in the basin respond chiefly to spring runoff, surface-water irrigation, and pumpage for ground-water irrigation.

A seepage study on the Weiser River indicates that very little relation exists between the surface- and ground-water resources except in the lower part of the basin.

Flow in Silver Creek

J. A. Moreland began a study to evaluate the relations between ground water and surface water in the Silver Creek area of Blaine County. A network of

about 75 wells has been selected for monthly water-level monitoring to document ground-water fluctuations. Much of the basic information on well construction, use of water, owner's name, and drillers' logs has been collected for entry into the computer file.

NEVADA

Water-resource appraisal of Carson River basin

The Carson River basin study area encompasses about 9,600 km² in western Nevada. According to P. A. Glancy and T. L. Katzer, estimated average annual inflows to the area during the 1919–69 study period are: (1) About 1,800 hm³ of precipitation, (2) 390 hm³ of Carson River flow from California, (3) 7 hm³ of Humboldt River tailwaste, and (4) 220 hm³ of water imported from the Truckee River drainage. Estimates of major annual outflow budget components include (1) an undetermined quantity of precipitation that evaporates, (2) about 370 hm³ of shallow ground-water evapotranspiration and consumptive crop use, and (3) about 310 hm³ of evaporation from surface-water bodies. However, the combined 1971 domestic, municipal, industrial, and livestock use was estimated at about 10 hm³. Available data suggest that, aside from riverflow, the Carson Valley ground-water reservoir at the upstream end of the area is the best available source of large quantities of high-quality water. In contrast, Carson Desert, at the terminus of the area, has a vast quantity of ground water in storage, but it is believed to be largely unacceptable for most uses. Intervening hydrographic subbasins generally have significantly large quantities of stored ground water of intermediate quality.

Effects of pumping on the water resources of Smith Valley

In 1972, inflow to Smith Valley in the West Walker River basin was below normal, and thus the supply of irrigation water available from the river was decreased. Supplemental water pumped from wells resulted in the net mining of approximately 7.4 hm³ of water from ground-water storage. According to F. E. Rush and C. V. Schroer, the ground water will be replenished by the large amount of infiltration of irrigation water to the water table during years of above-normal river flow.

OREGON

Ground water in the Columbia River Basalt Group on the Umatilla Indian Reservation

J. B. Gonthier reported that a local poorly defined zone of very low hydraulic conductivity occurs at depths between 60 and 110 m in the Columbia River Basalt Group aquifer on the Umatilla Indian Reservation just east of Pendleton. Ground water in the basalt above this zone is part of a shallow local flow system that discharges to the Umatilla River in winter and spring. Many wells tapping this shallow system at lower elevations in the Umatilla River valley, west of the Indian agency near Mission, flow under low head during that period. However, wells deeper than 110 m generally tap a regional flow system that is defined by static water levels more than 60 m below the land surface.

Ground water leaks downward from the shallow flow system to the deeper regional system through uncased wells. This leakage probably is increasing because the number of deep wells that penetrate both systems is increasing. Local permanent water-level declines in the shallow flow system could result, and movement of waterborne contaminants through the wells is also possible.

A local seasonal decline of ground-water levels results from the concentration of pumpage in a small area (secs. 4, 5, and 7–10, T. 2 N., R. 33 E.). Pumpage has gradually increased because of the growth of the population and the use of ground water for irrigation. Local declines are sufficient to require deepening of individual wells; as pumpage continues to increase, the problem will become more extensive areally.

Flow of the Warm Springs River

Studies on the Warm Springs Indian Reservation by Antonius Laenen and J. H. Robison showed that the Warm Springs River receives nearly all of its base flow from highly permeable young volcanic rocks in the Cascade Range. Little additional flow is gained after the river emerges from the mountain front onto the plateau formed on poorly permeable Tertiary rocks. Seepage measurements during a base-flow period showed that springs abruptly increased discharge of the river from 0.14 m³/s to 1.9 m³/s in one reach of less than 0.5 km.

Base flow of Lincoln County streams

Measurements made by Antonius Laenen and F. J. Frank showed that base flows are low for streams along the coast of Lincoln County. Variations in the

base flows and the yields of wells are directly related to local geology. The following table shows relative base flows of streams in several geologic units determined from a series of measurements made during September 1972:

Geologic unit	Age	Base flow ($m^3 s^{-1} km^{-2}$)
Tyee Formation (Sandstone)	middle Eocene	0.0005 to 0.002
Marine terrace deposits	Pliocene	0.0010 to 0.009
Siletz River Volcanics	early and middle Eocene	0.0050 to 0.007
Sand dunes	Quaternary	0.0060 to 0.016

During a higher base-flow period in August 1974, flows were measured in the Yachats River basin in southern Lincoln County. In that area, base flows from Eocene marine siltstones and sandstones were low (about 0.003 $m^3 s^{-1} km^{-2}$). The highest base flows, in streams along the contact between the marine sediments and Eocene basalts, were about 0.008 $m^3 s^{-1} km^{-2}$. Base flows from the basalts were slightly less, about 0.007 $m^3 s^{-1} km^{-2}$.

Diamond Lake inflow streams

Streams flowing into Diamond Lake show markedly different flow characteristics that reflect differences in the geology of their drainage areas. An evaluation by D. D. Harris of inflow to the lake for the 1972 and 1973 water years showed that runoff was exceptionally high in 1972 and very low in 1973. Long-term records for nearby streams indicate that runoff in 1972 was the second highest and in 1973 was the third lowest in more than 30 yr.

Silent Creek, the largest contributor to the lake, flows into the southern end of the lake from the water-retentive pumice-covered area on the slopes of ancient Mount Mazama north of Crater Lake. The mean flow of Silent Creek in the 1972 water year was 1.02 m^3/s, with a maximum daily flow of 1.44 m^3/s and a minimum daily flow of 0.91 m^3/s. In 1973, the mean flow was 0.93 m^3/s or 92 percent of the 1972 mean flow. The maximum daily flow in the 1973 water year was 1.13 m^3/s, and the minimum daily flow was 0.82 m^3/s. The second largest contributing stream is Short Creek, which also drains the pumice-covered area to the south and had average discharges of 0.40 m^3/s and 0.34 m^3/s in the 1972 and 1973 water years, respectively. The 1973 flow was 86 percent of the 1972 flow.

In contrast to the steadily flowing streams from the pumice-covered areas, streams that drain the area of less water retentive, older igneous rocks east and west of the lake have large variations in flow. The combined average discharge from these areas was 0.22 m^3/s in the 1972 water year compared with 0.008 m^3/s in 1973, only 4 percent of the 1972 flow. Mean monthly flows during the 2 yr varied from 0.71 m^3/s to no flow.

WASHINGTON

Seismic profile lines in the Spokane area

According to H. H. Tanaka, results of seismic observations along four profile lines in the Spokane and Little Spokane River valleys indicate that the crystalline and metamorphic bedrock underlying the unconsolidated gravel aquifer ranges in depth from less than 90 m to more than 360 m. A north-south profile line 3 km west of the Washington-Idaho border shows a V-shaped valley with bedrock 390 m deep about 1.6 km north of the Spokane River, between secs. 2 and 3, T. 25 N., R. 35 E. A northeast-southwest profile from the base of Five Mile Prairie across the Spokane River indicates that bedrock is over 270 m deep 300 m east of the river in sec. 28, T. 26 N., R. 42 E. An east-west profile in the Hillyard area shows bedrock about 240 m deep between secs. 20 and 21, T. 26 N., R. 43 E. A northeast-southwest profile line in the Little Spokane River valley shows that bedrock is less than 90 m deep beneath the river in sec. 3, T. 26 N., R. 42 E. Information from the seismic survey will be used to analyze the quantitative ground-water flow in the Spokane area.

SPECIAL WATER-RESOURCE PROGRAMS

SALINE WATER

Houston Ship Channel identified as source of saline water entering the Chicot aquifer in the Houston, Texas, area

Large ground-water withdrawals from the Chicot aquifer in the area of the Houston Ship Channel have caused artesian water-level declines of as much as 107 m, and saline water is now leaking into the aquifer from surface-water bodies. Results of water-quality studies by D. G. Jorgensen indicated that the Houston Ship Channel is the main source of saline water entering the aquifer and that simple dispersion (water mixing) is the main chemical-transport agent. A preliminary analysis of the data indicates that, although the ship channel is a source of contamination, saltwater intrusion has not yet caused a significant deterioration of water quality in the aquifer.

Freshwater-saltwater interface on Cape Cod, Massachusetts

M. H. Frimpter, J. H. Guswa, and C. J. Londquist reported that two groups of observation wells were

drilled during the initial phases of a program designed to locate and monitor the transition zone between freshwater and saltwater on Cape Cod.

In Wellfleet, wells were drilled in sand approximately 150 m from the high-tide line of Cape Cod Bay at depths of 9, 14, 21, and 29 m. The chloride concentrations in water samples collected from these wells were 58, 93, 8,100, and 11,000 mg/l, respectively, these values indicating that at this site the freshwater lens is about 15 m thick.

At Head of the Meadow in Truro, the wells were drilled approximately 150 m from the high-tide line of the Atlantic Ocean but less than 30 m from the edge of a salt marsh. At depths of 5, 12, 19, and 27 m, the chloride concentrations in water samples were 8,600, 4,500, 240, and 2,300 mg/l, respectively. The pattern of chloride concentration is evidence of the existence of the edge of a freshwater lens that is being recharged with brackish water from the tidal marsh. Similar conditions were observed in shallow wells, less than 2 m deep, in two tidal marshes.

Seawater intrusion in Dade County, Florida

Continuing studies of seawater intrusion by J. E. Hull and D. J. McKenzie (1974) indicated landward movement of the salt front during 1974 to within 1.4 km of the Miami-Dade well field in Miami Springs and into the well field at Homestead Air Force Base.

Saltwater-freshwater mapping, West Virginia

Structure contour maps of the upper surface of saline ground water in West Virginia show areas in which saline water occurs at shallower than normal depths. The "shallow" saline water occurs both naturally and artificially through upward migration resulting from man's activities. In stream and river valleys, saline water moves upward along faults or fracture zones from the connate brines that are present at depth. Oil and gas wells that were not properly cased or that have been abandoned and not adequately plugged have provided avenues for upward movement of saline water. Other occurrences of saline water at shallow depths are associated with subsurface disposal of brines from oil separators and the reduction in the freshwater head in valleys by the dewatering of permeable zones under adjacent hills where there are coal mines. J. B. Foster has been checking geophysical well logs and brine well data in an effort to differentiate areas of naturally occurring "shallow" saline water from areas that have been contaminated by industrial activities.

DATA COORDINATION, ACQUISITION, AND STORAGE

OFFICE OF WATER-DATA COORDINATION

Water-data coordination activities continued during the year with special emphasis on field coordination of data-acquisition activities, development of recommended methods for water-data acquisition, and preparation of hydrologic unit maps of the Nation. Closely related activities included implementation of river-quality assessment activities and the level I accounting network and further work on the design of NAWDEX.

The ninth meeting of the Interagency Advisory Committee on Water Data was held on October 22, 1974, in Reston. Members of the non-Federal Advisory Committee on Water Data for Public Use were invited to attend this meeting.

The "Summary of Plans for Acquisition of Water Data by Federal Agencies, Fiscal Year 1976," released in June 1975, contains a digest of plans for water-data acquisition in each of the 21 regions designated by the Water Resources Council (WRC) and information on activities of national scope as reported by officials at headquarters level. Activities covered during this field coordination cycle included specific plans on long-term stations for surface-water stage, flow, and quality and for ground-water quality and general information on other water-data needs. The field coordination activity planned for fiscal year 1977 was initiated in May 1975 to cover the same activities and to update the "Catalog of Information on Water Data." The 1974 edition of the catalog, prepared in 21 separate volumes corresponding to the water-data acquisition activities in the 21 regions, reflected activities as of January 1, 1974, for those stations being operated for a period of 3 yr or more. The new edition will contain a cross-reference list to tie the coding system (map number and letter used on the catalog station-location maps) to the new eight-digit hydrologic unit codes used on the State Hydrologic Unit Maps. The new State Hydrologic Unit Maps will replace the 1:1,000,000-scale station-location maps previously published (latest edition, 1972) in conjunction with the catalog.

The new series of USGS base maps, "State Hydrologic Unit Maps," prepared by the Office of Water Data Coordination in cooperation with the WRC, received the approval of the National Programs and Assessments Committee of the WRC. The first 27 of the 1:500,000-scale maps were published and are be-

ing sold by the USGS. The remaining 26 maps are expected to be published early in 1976.

The Coordinating Council for Water-Data Acquisition Methods, established in 1974 with A. I. Johnson as methods coordinator, held three meetings during the year. Sixteen agencies are now represented on the council, which met in October 1974 and February and June 1975 to plan and discuss participation of the working groups involved in developing the handbook of "Recommended Methods for Water-Data Acquisition," advise the working groups on their recommendations, and approve the outlines of the 10 chapters submitted by the groups. Ten working groups were established by the council to expand the handbook into 10 chapters covering (1) surface water, (2) ground water, (3) sediment, (4) biologic and bacteriologic quality of surface and ground water, (5) chemical, inorganic and organic, and physical quality of surface and ground water, (6) soil moisture, (7) basin characteristics, (8) evaporation and transpiration, (9) snow and ice, and (10) hydrometeorological observations. The groups held their initial meetings in Washington, D.C., from January 13 to 24, 1975; 120 participants represented 21 Federal agencies. The working groups met for 3 d of sessions and elected chairmen and vice-chairmen for their respective groups, prepared preliminary chapter outlines, assigned various tasks to the members, and prepared recommendations for action by the Coordinating Council. Non-Federal involvement in the recommended-methods activity was initiated by organizing the Ad Hoc Working Group on Recommended Methods, made up of nine members from the Advisory Committee on Water Data for Public Use. This group held meetings in February and May 1975, with the result that over 100 non-Federal experts and agencies were asked to review the detailed chapter outlines for the new handbook of "Recommended Methods for Water Data Acquisition."

The second 1-yr NAWDEX contract with Planning Research Corporation was completed in May 1975 and included the following: (1) Definition of the format and contents of a Master Water-Data Index and the procedures for its implementation, (2) development of a memorandum of understanding for participants, (3) identification of sources of water-related data, and (4) preparation of an operations manual for the system. In addition to the completion of contractual efforts, limited access to the data file of the National Water Data Storage and Retrieval System (WATSTORE) was made available to other Federal agencies and major non-Federal cooperators as of June 1, 1975. This access is initially restricted to the Station Header File and the Daily Values File of the WATSTORE system. A user's manual containing a detailed description of the WATSTORE files and complete instructions for access to the files was also developed and made available to all users of the system.

WATER-DATA STORAGE SYSTEM

The USGS uses a digital computer to process, store, retrieve, and display water-resource data. The computer is also used with water-resource studies that require capabilities in statistical and analytical techniques, graphical display and map presentation of data, and mathematical modeling of hydrologic systems. The computer system consists of a central computer located in Reston, Va., and remote terminal facilities located in 45 States.

Data on daily discharge, collected by the USGS and cooperating Federal and State agencies at about 10,000 regular streamflow stations, are stored on magnetic tape. The volume of data holdings is equivalent to about 280,000 station years of record. More than 78 percent of all streamflow data collected under this program are covered. The data are stored in discrete units containing figures for daily water discharge for each gaging station and for each year of record; 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 for storage and retrieval of surface-water-quality data has been in use since 1959. All data collected since then, plus selected long-term historical records, have been entered into the system. The system contains the following types of data: (1) Chemical and physical analyses of surface water, (2) suspended sediment, (3) water temperature, (4) specific conductance, and (5) multi-item data collected by digital monitors.

A new automated system for storage and retrieval of ground-water data has been introduced. The Ground-Water Site Inventory data base operates under a proprietary data-base management system that allows data retrieval on the basis of the values of about 30 key parameters. Information in the new file includes data on location, physical characteristics, construction history, geohydrology, aquifer characteristics, field quality determinations, water levels, and water withdrawals for wells, springs, or other sources of ground water. By the end of June 1975, records of about 100,000 wells and springs had been

converted from the older punch-card format and entered into the new system.

URBAN WATER PROGRAM

During 1975, the USGS continued its program of hydrologic investigations in urban areas. A. F. Pendleton, Jr., reported that 225 active projects were directly related to urban water problems, and many others were indirectly related to urban problems. The 225 projects represent about 20 percent of the total water-resource-investigation projects in progress during the year.

URBAN WATER-RESOURCE STUDIES

Alaska

G. O. Balding reported that a project is underway to develop ground-water resources in Mendenhall Valley for the city and borough of Juneau. In order to delineate the physical, chemical, and hydrologic properties of the aquifer, a 61-m-deep test well is being drilled in the glacial-outwash deposits in the valley. Drilling is being done by cable-tool methods, and cutting samples are being collected every 1.5 m or less. The well has been drilled to a depth of 26 m with 1.2 m of screen exposed between depths of 23.8 and 25.0 m in a zone of coarse sand and pea gravel. Observation wells have been drilled at distances of 30 to 46 m from the test well. Chemical analyses indicate a calcium bicarbonate type of water with low dissolved-solids concentrations (less than 100 mg/l) and dissolved-iron concentrations ranging from 40 to 1,100 μg/l.

According to C. E. Sloan, both surface and ground water are locally abundant in the area between Copper Center and Summit Lake. Surface-water flow approaches zero during the winter months in all streams except major rivers such as the Tazlina and the Gulkana. Turbidity affects water quality in glacial lakes and streams during the high summer-flow period. Color is high in sluggish streams, such as Sourdough and Haggard Creeks, that drain extensive muskeg or swampy areas. Most surface water is of a dilute calcium bicarbonate type, low in dissolved solids and usually clear. Summit and Paxson Lakes also contain dilute calcium-bicarbonate-type water that is very clear except in places near the major inflow areas, which temporarily increase in turbidity. Both lakes are thermally stratified by late summer, but they are near saturation with respect to DO throughout the water column during the entire year. Ground-water quality is poor in the central part of the Copper River basin, particularly in the vicinity of Glennallen, owing to high salinity and hardness.

L. L. Dearborn, Chester Zenone, and D. E. Donaldson reported significant results of their hydrologic studies at Anchorage. According to Dearborn, rapid residential growth in the Hillside area southeast of metropolitan Anchorage may cause depletion of aquifers and pollution of ground water as a result of extensive development of small-lot tracts. Ground-water yields are low and may even be inadequate for single-family requirements in some parts of the area. The low permeability of surficial glacial sediments limits the efficient operation of septic-tank systems in this unsewered residential area. Zenone concluded that the cumulative effect of reclamation of muskeg (swamp) terrain, installation of municipal sewers, and residential and commercial development practices have altered hydrologic-budget factors and caused declining water levels in Sand Lake, an urban lake in the Anchorage area. Donaldson reported that urban-area runoff into Sand Lake from melting snow and ice in March 1974 contained the following concentrations of toxic metals: 20,000 μg/l of Fe, 600 μg/l of Pb, and 40 μg/l of Cu. These concentrations greatly exceed the background levels of those constituents in the lake itself.

Water-availability studies in the Anchorage area, where a rapidly growing population is creating increased water demands, continued under the direction of G. S. Anderson. Artificial-recharge experiments have proved the feasibility of increasing potentiometric heads locally near production wells to augment their yields. Analyses of aquifer test data in the southern part of Anchorage indicate that a production well there would be capable of yielding 3.8 to 5.7 million litres per day.

G. W. Freethey reported that water supplies needed for expansion of fish-rearing facilities along the lower reaches of Ship Creek can probably be provided through the conjunctive use of water from the stream itself and the underflow in the alluvium adjacent to the stream channel.

Florida

An urban-hydrology study of the Tampa Bay region began in April 1974. Information collected as part of the study will provide a current data base on the quantity and quality of precipitation and streamflow for small urban watersheds under various types of development. Data that are synthesized by the use of urban watershed models will enhance planning and management evaluations and facilitate decisions re-

garding proposed future development and water-management alternatives.

G. E. Seaburn reported that current work activities include the planning and installation of data networks and the compilation of data describing watershed characteristics. Streamflow and rainfall instruments have been installed in 10 basins. Studies are underway to determine the feasibility of supplementing rainfall data with available radar imagery and to evaluate the use of automatic water-quality sampling equipment and continuous water-quality monitors to collect data on the chemical quality of rainfall and runoff. If currently available equipment does not prove reliable, samples will be hand collected at each stream site during storm periods.

L. V. Causey, R. B. Stone, and M. I. Backer prepared 18 maps (1:24,000 scale) that show geohydrologic information needed for urban land-use planning for an area of about 780 km^2 in the southwestern portion of Duval County. Recharge occurs in about 60 percent of the area; the water table is within 1.5 m of land surface in about 90 percent of the area; the potentiometric surface of the Floridan aquifer ranges from less than 7.6 m to about 18 m above sea level; land surface ranges from near sea level to 31 m; and artesian wells will flow in about 35 percent of the area. Drainage maps show basin divides, drainage areas, gaging sites, and the direction of surface runoff.

Maryland

W. F. White and E. G. Otton reported that concern over adequate domestic ground-water supplies and safe underground disposal of domestic sewage effluent in the Baltimore, Md., and Washington, D.C., areas has resulted in the preparation of a series of environmental geohydrologic maps at a 1:24,000 scale. These maps, beginning with the White Marsh, Md., 7½-min quadrangle prepared by Otton (1974), show areal geology, location of wells and springs, depth to water table, availability of ground-water supplies, and geohydrologic constraints on underground sewage disposal. The maps should be useful to local government agencies, engineers, planners, and members of the general public who are concerned about problems of water supply and sewage disposal in urban areas without public utilities.

Minnesota

D. C. Larson, S. P. Larson, and R. F. Norvitch used a variation of Darcy's law to determine the relative distribution of steady-state leakage downward to the Prairie du Chien-Jordon aquifer, the major aquifer in the Twin Cities metropolitan area. Available data and estimates of vertical hydraulic conductivity for geologic units indicate that major leakage to the aquifer occurs in formation subcrop areas, especially where these areas are overlain by the most permeable glacial drift. The relative distribution of additional leakage downward to the aquifer, resulting from increased pumpage during the summer, was also determined. Calculations indicate that 10 to 20 percent of the increased summer pumpage is derived from increased leakage. The remainder is probably from captured natural discharge and induced recharge from major streams within the influence of summer cones of depression.

URBAN RUNOFF AND FLOODS

Kansas

A flood-insurance study for Wichita was recently completed by D. B. Richards and C. O. Peek for the Federal Insurance Administration of HUD. Results of the study include (1) water-surface profiles of the 10-, 50-, 100-, and 500-yr floods, (2) water-surface contours of the 100-yr flood, (3) flood-hazard factors, and (4) the location of regulatory floodway boundaries (the 100-yr flood is the regulatory flood).

The index-flood method was selected for the study to determine the flood-frequency discharges (Q_{RI}) for ungaged stream sites and for varying degrees of urbanization (as measured by the percentage of the drainage area having an impervious surface) for the city of Wichita. The index flood is the 2-yr flood (Q_2). The basic curve of this method is the ratio of Q_{RI}/Q_2 (for rural conditions) versus recurrence intervals (RI). This curve was calculated after consideration of (1) statewide flood-frequency analyses and reports (including channel geometry), (2) application of the RAREVENT computer program (Carrigan, 1973), (3) analyses of flood-frequency results from basins in central Kansas with 30 or more years of homogeneous flood records, and (4) other published flood-frequency results.

Regression analysis of the 2- and 100-yr floods produced the generalized relationships for Q_2 and Q_{100} discharges in cubic metres per second. The functional relationships between the Q_{RI} and the contributing drainage area (A) in square kilometres and the percentage of the basin drainage area covered by impervious surface ($\%I$) are:

$$Q_2=2.77\ (A)^{0.60}\ (\%I)^{0.26}$$
$$Q_{100}=15.70\ (A)^{0.64}\ (\%I)^{0.17}$$

These results support conclusions from previous investigations, namely, that urbanization significantly

increases the magnitude of the 2-yr flood (two or three times) but has less effect on high-magnitude floods.

New Jersey

S. J. Stankowski (1974) developed a rapid and inexpensive technique for estimating flood-peak magnitudes having selected recurrence intervals ranging from 2 to 100 yr for drainage basins in New Jersey larger than 2.59 km^2 with various degrees of existing or projected urban and suburban development. Four parameters are required for use of the method. Three of these—basin size, channel slope, and surface storage within the basin—can be measured from topographic maps. The fourth is an index of manmade impervious cover that can be determined for existing and future development conditions from census data and population projections that are readily available from regional, State, and local planning agencies. This index is based on correlations between population density and the proportions of land area in each of six urban and suburban land-use categories found in 567 New Jersey municipalities with population densities ranging from less than 40 persons/km^2 to over 15,000 persons/km^2. By weighting the proportions of land use with average percentages of manmade impervious cover found in corresponding land-use categories, a relation was developed between population density and the proportion of manmade impervious cover resulting from different degrees of urban and suburban development. Mathematical relationships for estimating peak discharges for selected recurrence intervals were developed from thorough analyses of flood peaks and watershed characteristics for 103 sites in New Jersey. In the analyses, flood characteristics for each site were determined from frequency analysis of the annual flood-peak record and related by multiple regression to the characteristics of the watershed. Urban and suburban development is shown to increase flood peaks up to 3 times at the 2-yr recurrence interval and up to 1.8 times at the 100-yr recurrence interval as statewide averages.

New York

D. A. Aronson reported development of a mathematical procedure for analyzing the operating characteristics of storm-water basins on Long Island. By using finite-difference equations, maximum storage of storm runoff during theoretical high-intensity storms was determined for the typical storm-water basin in Nassau County. Analyses indicate that the test basin would fill to only 30 percent of available storage capacity during a storm having a recurrence interval of 100 yr, given an observed infiltration rate of 0.46 m/h. The apparently large safety factor inherent in this basin and similar basins on Long Island is due primarily to the fact that contemporaneous exfiltration (leakage losses) during inflow of runoff is not considered in basin-design criteria. The large unused storage capacity of many storm-water basins makes them well suited for the simultaneous recharge of highly treated waste-water and storm runoff, as long as infiltration rates at the basin walls are not reduced appreciably and waste-water storage is kept to a minimum.

Tennessee

According to H. C. Wibben, preliminary data indicate that urbanization in metropolitan Nashville will increase the magnitude of 2-yr-flood discharges about 30 to 40 percent and the magnitude of 100-yr-flood discharges less than 20 percent. Current development practices include very few improvements to the natural drainage systems; however, natural channel conveyance is quite good. Soils in Davidson County are thin and relatively impermeable, and rock outcrops are prevalent throughout most of the county. Consequently, the effects of urbanization upon flood discharges are less pronounced in Davidson County than those indicated by previous studies in other parts of the country.

QUALITY OF STORM RUNOFF IN URBAN AREAS

Florida

C. B. Sherwood, Jr., and H. C. Mattraw, Jr., reported that an automatic storm-data collection system is being used to collect rainfall, flow, and water-quality samples in a small residential area north of Fort Lauderdale. The study location is a moderate-density single-family residential neighborhood with swale drainage. Season, antecedent dry condition, and rainfall influence magnitudes of most water-quality parameters. Total coliform bacteria counts as high as 2 million colonies per 100 ml indicate that storm-water runoff is a major source of surface-water contamination.

HYDROLOGIC EFFECTS OF WASTE DISPOSAL IN URBAN AREAS

Alaska

Water-quality and lithologic data from test wells drilled in the city of Anchorage landfill indicate that it is highly unlikely that two nearby municipal wells will be polluted by leachate from the landfill, accord-

ing to L. L. Dearborn and D. E. Donaldson. Solid-waste disposal in this high-water-table area has caused serious localized pollution of shallow (0.6 m) unconfined ground water, but municipal-supply aquifers between depths of 55 and 100 m are confined beneath and protected from landfill pollutants by thick, poorly permeable clay-silt deposits.

Florida

H. J. McCoy and C. B. Sherwood, Jr., reported that shallow wells (Biscayne aquifer) were sampled in the vicinity of a proposed deep-injection well in Fort Lauderdale. A core hole was drilled to obtain detailed lithologic data on the aquifer to a depth of 61 m. Three salinity test wells were drilled to more accurately delineate the position of the saltwater front at depth in the Biscayne aquifer. Geohydrologic data on the deep Floridan aquifer were compiled and provided to the cooperator, the city of Fort Lauderdale, for use in preparation of injection-well plans.

The city of West Palm Beach, with financial assistance from EPA, is constructing a new secondary sewage-treatment plant to handle the increasing amounts of domestic waste water. EPA personnel have advocated disposal of the effluent by deep-well injection. F. W. Meyer and W. A. J. Pitt, Jr., as part of a cooperative program with the city, collected data from a 1,070-m-deep test well, presently under construction, to evaluate the capability of a saline, deep artesian aquifer to accept treated effluent.

Quarterly sampling of test wells located in and around the NW. 58th Landfill, Dade County, continued. Downgradient movement of a wide variety of landfill leachates has been established. J. E. Hull reported that most parameters of environmental concern have decreased to near-background concentrations within several hundred metres of the original deposition site.

New York

Results of a study of declining water levels in an 83-km^2 sewered area in Nassau County by M. S. Garber and D. J. Sulam showed that ground-water levels in the area have declined an average of 3.6 m relative to a nearby unsewered area to the east. Although sewering did not begin until 1953, water-level fluctuations were analyzed by the double-mass-curve technique for the period 1938–72 in order to establish a correlation between sewered and unsewered areas. Pumpage effect was evaluated with a five-layer analog model of the Long Island ground-water reservoir. Pumpage in adjacent Queens County accounted for 1.5 m of the 3.6-m decline. The remaining 2.1 m of decline is attributed to sewering. Streamflow in the study area has also declined as a result of lowered ground-water levels. Total storage in the ground-water system for the period 1953–72 is estimated to be 1.3×10^{8} m^3.

WATER USE

Effects of 1974 oil embargo on water use for electric-utility energy production

The USGS has published estimates of water use in the United States every fifth year since 1950 (C. R. Murray and E. B. Reeves, 1972). Interim estimates of water used in 1974 for thermoelectric-energy production (the largest withdrawal use) and hydroelectric-power production (a nonwithdrawal use) were made from the U.S. Federal Power Commission's (1975) preliminary data for 1974 power production.

Murray noted from the data that, although total electric-utility production in 1974 was about 1.865×10^{12} kWh (an increase of 0.5 percent over 1973), power output by fuel-burning plants declined to about 1.565×10^{12} kWh (1.3 percent less than 1973). An estimated 189 km^3 of water was used for thermoelectric-power production in 1973 (Murray, 1974). The 1973 estimate should also be representative for 1974; a 1.3-percent decrease is well within the probable range of error of the water-use estimate. In contrast, water use for thermoelectric-power production was 33 percent greater in 1970 than in 1965. Therefore, it appears that the 1973–74 oil embargo did strongly affect thermoelectric-power production and water withdrawals.

Nuclear fuel was used for about 7.2 percent of the thermoelectric power produced in 1974, a 35-percent increase over 1973. Nuclear powerplants use slightly larger amounts of water for power production than coal-, oil-, or gas-fueled plants. The increased nuclear-fuel use and its attendant larger water use can be ascribed in part to the oil embargo.

On the other hand, hydroelectric-power production in 1974, which was about 16 percent of total electric-utility power production, increased 10.5 percent over 1973. The quantity of water used in producing the approximately 0.300×10^{12} kWh of hydroelectric power was estimated to be about 4,600 km^3. Repetitive use of this water is evident—the amount used far exceeds the total annual runoff of about 1,650 km^3 in the conterminous United States.

Use of water for rice irrigation increases in the Grand Prairie area in Arkansas

H. N. Halberg reported that the amount of water used for rice irrigation in the Grand Prairie region

in Arkansas in 1974 averaged 665.5 mm and that the median value was 632.5 mm, although precipitation during the 1974 growing season was greater than normal. These values exceed the average of 558.8 mm and the median of 553.7 mm determined for 1928, 1929, and the period 1937–40 (Kyle Engler, D. G. Thompson, and R. G. Kazmann, 1945). In the area between Bayou Meto and the Arkansas River, the amount of water used for rice irrigation averaged 952.5 mm, and the median value was 858.5 mm in 1974.

Water supply and demand in the Minneapolis-St. Paul metropolitan area

R. F. Norvitch reported that per capita use of both surface water and ground water in the Minneapolis-St. Paul, Minn., metropolitan area increased from 240 l/d in 1900 to 680 l/d in 1970. Total surface-water use in 1970 (exclusive of thermoelectric-power use) was 5.81 m^3/s, whereas total ground-water use was 8.98 m^3/s. Future demand on both water sources by the year 2000 is estimated at 26.2 m^3/s, or about 760 l/d per person.

Total average streamflow, gaged near where the three major streams enter the metropolitan area, is about 232 m^3/s; however, during times of extremely low flow, there is not enough water available to fully satisfy all demands. About 43.8 m^3/s of ground water can be obtained by increasing pumpage in both the Prairie de Chien-Jordan and the Mount Simon-Hinckley aquifers. This water would partially compensate for surface-water shortages during extended low-flow periods.

Use of water from public supplies in southwestern Pennsylvania

The jurisdictional and developmental complexities of providing water service to municipal areas are graphically illustrated in a 1:125,000-scale map by R. M. Beall (1974). The map shows areas serviced by water-supply agencies within the 11,650-km^2 six-county greater Pittsburgh region in southwestern Pennsylvania. Selected data for the 153 systems mapped show that more than half serve fewer than 1,000 residential customers; only 11 systems serve more than 10,000 residential customers. Residential water use within the 11 largest systems accounts for 37 percent of the water used; the remainder is distributed among commercial, industrial, and other customers and bulk sales and systems losses. Data collected during the study show that the proportion of water used by the several classes of customers varies widely among systems. The total estimated average water use in 1973 by all listed systems was about 1,400,000 m^3/d. Privately supplied domestic, commercial, industrial, and institutional systems, which used water at perhaps 10 times the rate of public systems, were not included in the assessment.

COORDINATE WATER-QUALITY PROGRAMS

Significant advances have been made in the implementation of the National Stream Quality Accounting Network (NASQAN), part of the level I accounting element of the National Water Data Network. J. F. Ficke reported that, during the 1975 fiscal year, 245 stations were added to NASQAN, this addition bringing the network to a total of 345 stations, 66 percent of the ultimate design size of 525 stations. T. D. Steele, E. J. Gilroy, and R. O. Hawkinson (1974) analyzed temperature and chemical-quality data from 88 NASQAN stations and detected significant long-term changes in temperature at 15 of 80 stations and significant changes in dissolved-solids content at 15 of 88 stations. According to R. J. Pickering, NASQAN is designed to report annually on the quality of the Nation's surface water and to give an accounting of water discharge and loads of selected constituents for each of the 330 river-basin accounting units. Stations are now operating in each of the accounting units. Details of NASQAN design are described in a report by Ficke and Hawkinson (1975).

During fiscal year 1975, the National Pesticide Water Monitoring Program, a subnetwork of NASQAN operated cooperatively by the USGS and EPA, was fully implemented to include quarterly sampling of water and bottom sediment at 153 NASQAN stations by district personnel of the USGS Water Resources Division. Each sample was analyzed for about 20 different pesticide compounds by Han Tai and his staff at EPA's pesticide laboratory at Bay St. Louis, Miss.

Since 1967, the USGS has operated a Hydrologic Bench-Mark Network designed to provide continuing uniform data on streamflow and water quality in more than 50 small stream basins that are expected to remain in their present natural condition. In a study of water-quality data for bench-mark stations, J. E. Biesecker and D. K. Leifeste (1975) reported that, although natural water quality generally is very good, a sample from Bear Den Creek near Mandaree, N. Dak., contained 3,420 mg/l dissolved solids. This high concentration in the "natural" environment illustrates the difficulty of distinguishing between manmade pollution and natural water quality and indicates that natural processes

can be principal agents in modifying the environment. Biesecker and Leifeste also observed widespread but very low-level occurrence of pesticide residues in the natural environment. On the other hand, of 642 analyses for minor metals, about 65 percent were below the level of detectability. The dissolved-solids content and the relative abundance of the major chemical constituents clearly reflected the type of rock underlying the stream basin.

As part of a continuing activity to provide statistical techniques for data analyses and evaluation of water-quality networks, T. D. Steele (1974) further developed and documented a harmonic-analysis technique for depicting the seasonal variability of stream temperatures; his computer program contains options for assessing the effects of reduced sampling schedules on annual stream-temperature depiction and for analyzing the serial dependence of continuous records and harmonic residuals. T. D. Steele and T. R. Dyar (1974) reported on the application of this technique to temperature data for streams in Georgia. Nonparametric tests were used by S. P. Larson, W. B. Mann IV, and T. D. Steele (USGS) and R. H. Susag (Twin Cities Metropolitan Sewer Board) (1974) to statistically determine significant long-term trends and make various graphic depictions of water-quality records for the Minneapolis-St. Paul, Minn., metropolitan area. Steele has also demonstrated the utility of a bivariate-regression model for taking advantage of correlated inorganic chemical-quality variables by using several foreign data sets.

The intensive river-quality assessment of the Willamette River basin in Oregon continued with the assistance of the ad hoc Working Group on River Quality Assessment of the USGS Advisory Committee on Water Data for Public Use; the field work for the Willamette River study was completed during the year. River quality in two additional river basins—the Chattahoochee River basin in Georgia and Alabama and the Yampa River basin in Colorado and Wyoming—is being intensively studied.

In 1975, the Central Laboratory System (composed of the Doraville, Ga., Salt Lake City, Utah, Albany, N.Y., and Denver, Colo., facilities) analyzed some 100,000 water-quality samples. About 1.2 million individual tests were performed, an increase of 50 percent over the number performed in 1974. The increase in sample analyses resulted from new energy studies and from other expanded district and Federal program activities. Federal programs produce about 15 percent of the total sample load for the Laboratory System, and district needs contribute 85 percent. The Central Laboratory System has the analytical capability to routinely perform about 400 different tests on water, sediments, and biota.

INTERNATIONAL HYDROLOGICAL DECADE, 1965–1974

The 10-yr program of cooperative international studies in scientific hydrology, known as the International Hydrological Decade (IHD), drew to a close on December 31, 1974. However, the United States, together with many of the approximately 100 other countries participating in the IHD program, will continue its studies as part of the International Hydrological Program (IHP), which will be sponsored by UNESCO.

Following a recommendation of the Panel on Post-Decade Procedures of the U.S. National Committee for the IHD, the USGS was given the responsibility for the guidance and operational direction of the IHP. A secretariat for U.S. IHP activities will be established in the Office of International Activities of the Water Resources Division at the USGS National Center in Reston, Va.

During the year, USGS scientists continued their participation in the IHD program. The network of 82 river stations that observe and record streamflow, chemical quality, and suspended-sediment load was maintained. This network provides a general index of the discharge of surface water and of the discharge of dissolved and suspended material from the continent to the oceans. Collection of hydrologic data also was continued at 23 lake and reservoir stations and at 34 selected observation wells; these stations provided information on water-level fluctuations and on the chemical quality of lake, reservoir, and ground water.

Hydrologic bench marks established early in the decade provide continuing information at 46 localities throughout the country on natural hydrologic conditions largely removed from man's activities. Measurements of the tritium content of water in the 20 principal rivers in the United States and of the tritium in precipitation at 16 localities are being used to evaluate the effects of precipitation on the chemical character of inland waters.

Observations at all of these stations will be continued as part of the United States effort in the IHP.

During the year, USGS hydrologists participated in international meetings of working groups, intercountry exchange of experts, discussions of selected activities chosen for particular years, and hydrologic research at selected areas in the United States where

the results are expected to have international interest or application.

I. J. Winograd participated in the International Symposium on the Hydrology of Volcanic Rocks, March 4–8, 1974, on Lanzarote, Canary Islands, sponsored by UNESCO, the United Nations Development Program, and the Spanish Government.

E. L. Hendricks served as one of the vice-chairmen at the ninth and final session of the Coordinating Council for the IHD at UNESCO House in Paris, August 29–30, 1974.

Hendricks also was Chief of the U.S. delegation to the End-of-Decade Conference on the Results of the IHD and on Future Programs in Hydrology, also held at UNESCO House from September 2–14, 1974. R. L. Nace (1974) and J. S. Cragwall, Jr., participated in the conference as members of the U.S. delegation.

During the conference, the Tercentenary of Scientific Hydrology was celebrated September 9–12, 1974. Nace presented a report, "General Evolution of the Concept of the Hydrological Cycle."

During the End-of-Decade Conference, two symposia were sponsored by the International Association of Hydrological Sciences (IAHS). H. P. Guy, R. F. Hadley, and R. H. Meade, Jr., presented reports at the Symposium on Effects of Man on Erosion and Sedimentation, and H. H. Barnes, Jr., and G. F. Smoot presented reports at the Symposium on Flash Floods. Barnes also served as a reporter at the sessions.

Nace continued his IHD activities as a member of the Working Group on Water Balances. During the year, he contributed some minor revisions and additions to the compendium report on the world water balance.

R. E. Oltman and A. I. Johnson participated in the IAHS Bureau meeting held in Paris during the End-of-Decade Conference. Johnson acted as U.S. coordinator for the Tercentenary of Scientific Hydrology and its symposia.

R. L. Cory continued water-quality monitoring and studies of the epifauna in the South, Rhode, and West Rivers, small estuarine tributaries on the western side of Chesapeake Bay in Anne Arundel County, Md. E. J. Pluhowski continued related studies on radiation balances in the same estuaries.

G. H. Davis served as Chairman of the UNESCO IHD Working Group on Ground-Water Studies until the IHD ended in December 1974. Davis was also a member of the Working Group on the Application of Nuclear Techniques in Hydrology and served with W. S. Keys and F. J. Pearson, Jr., of the U.S. National Committee for the IHD.

G. C. Taylor, Jr., was appointed to the IHP Panel of Editors for the "Guidebook on Ground-Water Studies."

The two IHD programs on snow and ice continued under the direction of M. F. Meier until the end of the IHD. Reports on the ice and water balances of Gulkana, Wolverine, South Cascade, and Maclure Glaciers for the 1967 water year were prepared, and a streamlined program for the publication of data for subsequent years was designed by R. M. Krimmel, L. R. Mayo, and W. V. Tangborn. An inventory of the multitude of small glaciers and tiny masses of perennial ice in California is being completed by Austin Post (USGS) and W. H. Raub (San Jose State College).

G. L. Faulkner participated in the bilateral U.S.-Yugoslavia Seminar on Karst Hydrology and Water Resources, held in Dubrovnik, Yugoslavia, June 2–7, 1975, and presented a report titled "Flow Analysis of Karst Systems with Well-Developed Underground Circulation."

R. F. Hadley, chairman of the U.S. National Committee for the IHD Work Group on Representative and Experimental Basins, assisted in the preparation of a final report of the group's activities; he summarized accomplishments of the small-basin hydrology programs in the United States during the IHD.

MARINE GEOLOGY AND COASTAL HYDROLOGY INVESTIGATIONS

MARINE AND COASTAL GEOLOGY

The continental margins are an important potential source of the fuel and raw mineral resources required by our growing and increasingly urbanized population. Knowledge of the geology, mineral resources, geologic processes, and environmental relationships of the coastal zones, the adjacent shelves, and the deep ocean is urgently needed to solve the problems generated by the increased and often competitive demands placed on the resources of these regions.

The USGS is continuing its diversified geologic investigations in the marine environment surrounding the Nation. Studies are being conducted in the Atlantic, Gulf of Mexico, Pacific, and Alaskan continental margins and in the Caribbean Sea. Participation in the International Decade for Ocean Exploration and the DSDP has extended these studies to the deep ocean as well. Many of the investigations involve cooperative arrangements with other Federal agencies, State governmental agencies, universities, oceanographic institutions, and international organizations. Results of the past year's research programs in marine and coastal geology are summarized below.

ATLANTIC CONTINENTAL MARGIN

SHELF GEOPHYSICAL, STRUCTURAL, AND RESOURCE STUDIES

In the past 3 yr, J. C. Behrendt and J. S. Schlee obtained multichannel (24 and 48) common-depth-point seismic profiles from the coast to a 4500-m water depth between Georges Bank and Florida. The surveys show a thick section of presumed Mesozoic to Cenozoic sedimentary rock beneath Georges Bank and the Baltimore Canyon Trough off Delaware and New Jersey; this rock has seismic velocities of 5 km/s in its lower part. These velocities, typical of carbonates, were interpreted in previous seismic refraction studies as being those of crystalline basement rocks. The new seismic data do not support the existence of the basement ridge postulated to exist beneath the Outer Continental Shelf off Maryland but do correlate with a platform 6 km beneath the outer shelf off New Jersey. The platform is inferred to be an Upper Jurassic or Lower Cretaceous carbonate horizon or reef, and weak reflectors are observed beneath it. Along the outer shelf off Georges Bank, the seismic data suggest an irregular ridge at a depth of 3 km that may be associated with the intersection of a fracture zone (New England seamounts) and the continental margin.

Profiles across Georges Bank east of New England show up to 8 km of sediments of probable Mesozoic and Cenozoic age in the ridge-bounded basin. Seaward of the ridge, beneath the lower continental slope and rise, about 4 to 5 km of sediment of presumably the same age overlie oceanic basement. The northeasterly trending Baltimore Canyon Trough thickens to over 12 km seaward of New Jersey, Delaware, and Maryland but is broadly warped by an igneous intrusion to the north. Off Maryland, the sedimentary accumulation is a wedge that thickens in a seaward direction and appears to be faulted beneath the continental slope; this section of the rise and lower slope is thicker (6 to 7 km) than that off New England. The sedimentary wedge and trough north of Cape Hatteras are interpreted to have formed after rifting of North America and Africa.

SHELF ENVIRONMENTAL STUDIES

H. J. Knebel estimated the within-station variance to show which of 31 variables are likely to be effective indicators of textural differences within the Baltimore Canyon Trough area on the Atlantic Continental Shelf. The variables that are most diagnostic of differences between stations are the percentages of gravel and sand, median and mean phi sizes, skewness, kuttosis, and percentages of coarse, medium, and fine sand. Some of the ¼-phi-sized fractions within the sand range cannot define areal trends effectively. The textural variability within the Baltimore Canyon Trough area reflects the reworked and sorted sediments that cover this part of the shelf and that differ from the more gradational sediments that

overlie areas like the Continental Shelf off Washington State. The magnitude of the within-station variance is not only important geologically, but it also has environmental and legal ramifications for any study that characterizes shelf areas with economic potential.

GULF OF MEXICO AND CARIBBEAN CONTINENTAL MARGIN

GEOPHYSICAL, STRUCTURAL, AND RESOURCE STUDIES

Salt structures and petroleum migration in the Gulf of Mexico

R. G. Martin, Jr., studying the continental margin of the northern and western Gulf of Mexico, found it composed of thick transgressive and regressive sections of Tertiary and Quaternary classic sediments deposited in offlapping wedges over mainly carbonates of Cretaceous age. Large volumes of salt beneath these deposits have played an important role in the morphological development of the gulf basin. In the northern gulf, salt masses and shale ridges have pierced and uplifted the sedimentary prism from DeSoto Canyon to northern Mexico and from the coastal plain to the foot of the continental slope. These diapirs end abruptly along the Sigsbee and Rio Grande Escarpments.

Salt domes beneath the northern gulf margin can be grouped into morphological belts. Deep-seated salt chimneys dot the inner shelf and adjacent coastal plain, broad isolated salt stocks characterize the middle shelf region, and broad semicontinuous diapiric uplifts associated with shale masses dominate the outer shelf and upper slope. Virtually the entire continental slope from the Mississippi fan to northeastern Mexico is underlain by massive salt structures that interconnect at relatively shallow subbottom depths. Salt structures on the middle slope appear as very broad flat-topped steep-flanked massifs; structures under the lower slope are large pillowlike swells between broad sedimentary basins in shallow depressions in the salt mass.

The grouping of salt structures by relief, size, and shape in the northern gulf region defines belts of decreasing diapiric maturity from the coastal plain to the foot of the continental slope. The least mature features in the cycle of salt tectonism in the northern gulf are the Sigsbee Escarpment south of Texas and Louisiana and the Rio Grande Escarpment to the west. They represent the fronts of an advancing salt "wave" that is responding to the load of sediments accumulated in the gulf coast geosyncline.

C. W. Holmes analyzed samples from 330-m drill holes on the Outer Continental Shelf and upper continental slope of the Gulf of Mexico. Sediments from these features show significant mineralogical and chemical variations, although the similarity of sediment types suggests constant sedimentation at least since Pliocene time. In the sediments over the salt intrusions on the outer shelf, the abundance of expanded clays (17 A) compared with that of the nonexpanded material (10 A) decreases with depth. Correspondingly, the cation exchange capacity and total organic content decrease with depth. These trends were not detected in the sediments away from salt structures. The chemistry of the "pore water" and trace metals adsorbed on the clay material reveals that a diffusion gradient has become established. The driving forces appear to be heat diffusion from the salt masses plus the migration of the extracted water from the collapsing clay minerals. These reactions have significant effects on the trace-metal content and the anthropogenic mineral composition of the sediments; they also appear to be important in hydrocarbon migration.

Caribbean tectonic map

Compilation of a preliminary geologic-tectonic map of the Caribbean region was nearly completed during 1974 by J. E. Case. Analysis of the combined onshore-offshore data provides a generalized chronology for many of the younger deformed belts of the region. Neogene to Holocene fold belts extend (1) from the southern margin of the eastern Cayman Trench through Hispaniola and along the southern borderland of Puerto Rico to Anegada Passage; (2) along the Venezuelan-Colombian borderland into the Sinu-Atlantico basin of Colombia; (3) along the northern Panama borderland into the Limon basin of Costa Rica and Panama; and (4) east of the Lesser Antillean arc from Anegada Passage to the delta of the Rio Orinoco. "Laramide" folds of the Yucatan Peninsula and northern Guatemala extend offshore along the Yucatan borderland to northern Cuba and probably eastward to the Virgin Islands. "Laramide" deformation of northern South America can be traced eastward to at least Tobago and probably to Barbados. For the most part, the interior Yucatan, Colombian, and Venezuelan basins have been tectonically stable during Neogene to Holocene time.

Modern uplift of Antillean arc

The most recent tectonic movement on the northern Antillean island arc appears to be a differential axial uplift, at least in the Mona Passage area, between Puerto Rico and the Dominican Republic. The

Isla de Mona lies in the middle of the passage but south of the east-striking tectonic axis. A modern sea-level nip is strongly developed on all the limestone cliffs of the island, as well as on its neighbor Monito, and small remnants of a fossil-elevated nip are preserved in the cliffs at scattered localities. Careful measurement of the height of the fossil nip by J. V. A. Trumbull (USGS) and R. W. Rodriquez (Puerto Rico Department of Natural Resources) demonstrates an upward tilt toward the north of the island during the unknown but clearly short time between the formation of the two nips. The tilt gradient at the island is 0.4 m/km, and linear projection north to the tectonic axis gives an uplift there of 24 m. No time base with which to measure the tilt rate has been established. However, most talus blocks show a fully developed modern nip; hence, formation of the nip must be rapid. The rate of cliff spalling is unknown.

COASTAL ENVIRONMENTAL STUDIES

Submarine valleys off Puerto Rico

Numerous uniformly developed submarine valleys indent most of the insular slope along the northern coast of Puerto Rico. J. V. A. Trumbull and Jose Muniz (USGS) and R. W. Rodriguez (Puerto Rico Department of Natural Resources) found that each present-day river mouth on the northern coast has a corresponding submarine valley but that there are many more submarine valleys than river mouths. These "extra" submarine valleys are located off known or highly plausible former locations of river mouths and may be a direct guide to previously unknown locations of former river mouths. This new information, when fully studied, will contribute to the knowledge of the geomorphic history of Puerto Rico.

Mercury in Matagorda Bay, Texas

C. W. Holmes found that the mercury content in the sediments of the Matagorda Bay system was anomously high in certain regions. These mercury-rich sediments accumulated because of tidal currents in the major channels of the bay and the general sedimentological regime of the bay. In this system, the tidal currents remobilized the mercury through a combination of biochemical and physical factors and thus reintroduced the mercury into the estuarine circulation in a region where the turbidity maximum was most prevalent. As a result, the mercury-rich sediments accumulated in the upper reaches of the bay.

PACIFIC CONTINENTAL MARGIN

Geophysical computer-processing equipment

D. H. Tompkins was engaged in designing a marine-integrated data acquisition and processing system (MIDAP) to be used in exploring the geology and geophysics of the Outer Continental Shelf and adjoining deep-sea areas off the Western United States. The system will be located aboard the USGS RV *Samuel P. Lee* and will construct the geologic structure of these offshore regions from measurements of the Earth's magnetic and gravitational fields, deep-penetration multichannel seismic reflection profiles, bathymetry, and high-resolution profiles of the upper hundred metres of sea floor.

Since the MIDAP system will provide real-time processing of these data types, on-board scientific personnel will be able to interact with the processing and receive graphical representations of processed data as required. MIDAP is intended to provide the scientist increased field flexibility by producing a controlled real-time look at his data while the ship is underway.

GEOPHYSICAL, STRUCTURAL, AND RESOURCE STUDIES

Southern California borderland

On the basis of recent geophysical and sampling cruises in the California continental borderland, J. G. Vedder, J. C. Taylor, and G. W. Moore compiled new maps that show the distribution of rocks by age. Of particular interest are the pre-Miocene rocks, which include basement rocks of probable pre-middle Cretaceous age and marine strata that have been paleontologically dated by R. E. Arnal and J. D. Bukry as middle Cretaceous, Late Cretaceous, Eocene, and Oligocene. The basement rocks consist of diverse types that show no detectable regional zonation and include zeolite-bearing wacke and argillite, blueschist, greenschist, amphibolite, pyroxenite, serpentinite, and saussuritized gabbro. Strata older than early Miocene have not been found in depositional contact on exposed basement ridges.

Miocene strata in the region south of the northern island group seem to be limited to the Santa Rosa-Cortes Ridge and the San Nicolas and Santa Cruz basins, where subsurface interpretations on sparker records have been made by Arne Junger and H. C. Wagner. Upper Albian to lower Turonian claystone has been cored from the unnamed ridge that forms the southwestern flank of Tanner basin, and Upper Cretaceous siltstone is present on the knoll 25 km west of San Nicolas Island. Eocene strata probably

are confined to the area encompassed by the Santa Rosa-Cortes Ridge and the Santa Cruz-San Nicolas basin systems. Marine claystone of Oligocene age is present at Cortes and Tanner Banks and directly south of Santa Rosa Island, but correlative nonmarine beds, which are widespread on the mainland, have not been found in the borderland.

Paleogeographic reconstructions of Paleogene strata by D. G. Howell suggested large-scale post-Eocene lateral dislocations in the borderland and adjacent areas. However, the apparent lack of regional zonation in the metamorphic rocks precludes interpretive restoration of the basement terranes to their pre-Tertiary positions until more work is done.

Central California

The large shelf basins off the central California coast, including the Santa Maria, Santa Cruz, Outer Santa Cruz, Bodega, and Point Arena basins, originated in the late middle Miocene, according to oil-company drilling results reported by Hoskins and Griffiths (1971). E. A. Silver determined that this timing coincides with a change in the direction of motion between the Pacific and American plates from about N. 22° W. earlier than 10 m.y. to N. 38° W. between 10 and 5 m.y. and N. 37° W. later than 5 m.y. These changes predict extensional movement across earlier, more northerly trending boundary faults; seismic reflection studies show that faults along the edge of major basins have this same trend. The reported synchroneity in the ages of formation of these shelf basins is explained more easily by a regional tectonic event related to changing plate motions than by local events or time-progressive tectonics such as migrating triple junctions.

H. G. Greene and J. C. Ingle, Jr., found that benthic foraminiferal assemblages of rocks dredged from Monterey Bay represent greater depths than their present occurrence; this discovery suggests a late Pliocene-early Pleistocene uplift within the center of the bay. Pleistocene megainvertebrate and microinvertebrate fauna collected in this region and analyzed by W. O. Addicott and J. C. Ingle, Jr., suggested a Pleistocene paleoclimate much cooler than today's and marine water conditions similar to those of the present Bering Sea.

Washington

Geologic mapping by P. D. Snavely, Jr., and J. E. Pearl, supported by paleontological studies of foraminifera by W. W. Rau, progressed on the so-called Tertiary core rocks of the Olympic Mountains in northwestern Washington. These strata record two major orogenic events that may reflect convergence between the Juan de Fuca and American lithospheric plates. The earliest period of inferred underthrusting involved middle and middle upper Eocene deep-water turbidites and siltstone, which are intensely deformed and cut by landward-dipping thrust faults. This assemblage is represented by mélange, composed of sheared middle Eocene siltstone with exotic blocks of lower Eocene basalt, large infolded blocks of turbidite sandstone, and broken formations. The first compressional tectonic event was followed by regional subsidence and unconformable deposition of deep-water marine siltstone and sandstone (of latest Eocene to middle Miocene age) on newly formed lower Tertiary "orogenic crust." In late middle Miocene, renewed underthrusting along the plate boundary is inferred to have reoccurred, and the upper Eocene to middle Miocene strata were strongly deformed by the second episode of compressional folding and thrusting.

In offshore basins, these structurally complex middle Tertiary sedimentary rocks are unconformably overlain by uppermost Miocene and Pliocene siltstone and sandstone, which are gently folded except where they have been penetrated by shale diapirs.

COASTAL ENVIRONMENTAL STUDIES

San Francisco Bay

D. H. Peterson, T. J. Conomos, W. W. Broenkow, and E. P. Scrivani, utilizing dissolved silica as a tracer of seasonal nonconservative processes in the San Francisco Bay estuary, found that physical (conservative) processes have a strong influence on nonconservative distributions. For example, the effects of time-dependent phytoplankton processes are partly controlled by the physically controlled variations in water residence time. River discharge provides a seasonal modulation of residence time in the estuary. Estuarine circulation imposes a spatial variance. Thus, it seems that both of these factors should be considered in developing mathematical models of processes that relate to the distribution of nonconservative properties such as phytoplankton.

D. H. Peterson and T. J. Conomos found that the lack of long-term current velocity and salinity field observations representative of a variety of spatial, tidal, wind, and river discharge conditions is the major difficulty in quantifying physical processes influencing the nontidal circulation in San Francisco Bay. One of the more detailed surveys (State of California, 1955) is located along one cross-channel

section near the head of the estuary (null zone). The data include near-hourly current velocity and salinity observations taken over a 2-week period at 14 stations and 2 depths and therefore provide an opportunity to estimate the tidal and nontidal contributions to the freshwater and salt flux.

As expected, preliminary results indicate that the salt flux is dominated by processes of tidal periodicity. Nontidal contributions associated with the influence of the density current were found to be negligible because these currents are weak (approach zero) in the null zone.

Results not anticipated were that the mean seaward water flux attributed to the compensation current for landward transport by the tidal wave was large, equivalent to a river current produced by a freshwater discharge of 170 to 230 m/s. For comparison, the freshwater discharge during this period, estimated from river hydrograph data, varied from 130 to 250 m/s. These river hydrograph data showed almost no relation to the freshwater discharge variations estimated from the cross-channel survey data. From this anomalous behavior, it appears that nontidal currents near the null zone are not dominated directly by river flow during low river discharge conditions.

Oregon-Washington

H. E. Clifton observed on a variety of coasts—the open coast of southern Oregon, the southeastern coast of Spain, the eastern coast of Florida, and sandy beaches in Willapa Bay, Wash.,—that a consistent pattern of sand bed forms develops in response to shoaling waves. The pattern can be illustrated by a model controlled by four variables: maximum orbital water velocity at the sea floor, asymmetry of this orbital velocity, wave period, and sediment grain size. Ripples and megaripples consistently tend to be asymmetric where the landward component of orbital velocity exceeds the seaward component by 5 cm s^{-1}; where the difference in velocity is less than 1 cm s^{-1}, structures consistently tend to be symmetric. Within the symmetric ripple field, the size of the ripples depends directly on the orbital diameter of the water motion if the ratio of orbital diameter to grain diameter is less than 1,000 and directly on grain size if this ratio exceeds 5,000. The size of symmetric ripples is gradational from the largest to the smallest ripples. In contrast, the size of asymmetric ripples may increase abruptly as velocity increases, similar to changes in size of structures produced by unidirectional flow. Asymmetric ripples migrate in the direction of wave propagations, whereas symmetric ripples may remain in place as long as the generating waves do not change significantly. Both symmetric and asymmetric bed forms convert to a flat bed as sheet flow develops at higher orbital velocities. The relationships within the model provide a means of interpreting ancient wave-worked sediment and identifying active processes in the present-day marine environment.

ALASKA-ARCTIC CONTINENTAL MARGIN

GEOPHYSICAL, STRUCTURAL, AND RESOURCE STUDIES

Gulf of Alaska

Preliminary interpretation of deep geophysical data in the northeastern Gulf of Alaska by T. R. Bruns and R. E. von Huene indicated that the area is structurally complex and consists of several areas with markedly differing structural styles. Complexity appears to increase from east to west.

Between Cross Sound and Icy Bay, there is only one structural high, the Fairweather ground, a large shelf-edge arch that roughly parallels the coast. Deformed rocks, probably of Late Cretaceous to early Tertiary age, crop out in the core of the arch. The rest of the area is underlain by a broad basin whose axis lies near the coast. Between Icy Bay and Kayak Island, the shelf is underlain by two types of structures. The first type is a series of asymmetric linear folds whose axes trend northeast obliquely across the shelf. These structures are apparently less complex than those on the adjacent land areas, although some of the offshore anticlines are bounded on the southeast by northwest-dipping overthrust faults. The second type is a large shelf-edge arch between Kayak Island and the Bering Trough. Its axis strikes parallel to the coast and has a very gentle surface dip. Between this arch and the coast is a broad downwarp as much as 95 km wide, perhaps containing some local unwarped areas.

The shelf between Kayak and Middleton Islands includes a broad zone of complex structures trending northeast, subparallel to these two islands and to the Aleutian Trench. Structural highs tend to be asymmetric and bounded by thrust faults on their southeastern limbs. Uplift and deformation are greater than those of the Icy Bay structural trend features. The crests of many of the highs appear to be eroded and truncated, and thus complexly deformed Tertiary rocks are exposed at the sea floor. Northwest of Middleton Island, there are two large northwest-trending structural highs separated by a deep basin. These structures, which have trends divergent from

those of Icy Bay and Kayak and Middleton Islands, show severe deformation on the flanks, and no structure is resolvable within their cores. Middleton Island lies on the northwestern flank of a large northeast-trending anticline and appears to be separated from the northwest-trending structures by a relatively deep basin. Shoreward of the Kayak-Middleton structural zone, acoustic basement appears to be high, and structure is not well defined by the marine data. This area includes much of the Hinchinbrook Seavalley, the Tarr Bank, and the Copper River Delta.

Sound penetration on the seismic reflection profiles is generally less than 1 s (one-way time) and is probably only within rocks of late Miocene age and younger. Like the adjacent onshore geology, the deeper structure offshore may be markedly more complex than near-surface structure.

Bering Sea

D. W. Scholl studied seismic reflection records collected by the U.S. Naval Oceanographic Office and found a number of strong reflectors of "bright spots" within the sedimentary section of the northern Aleutian Basin in the Bering Sea. The bright spots and the anomalous deformed structures beneath them may be indicative of significant hydrocarbon deposits.

A. K. Cooper interpreted the magnetic data in the Bering Sea basin and noted a series of north-south oceanic-type magnetic anomalies. These anomalies have been provisionally dated as 117 to 132 m.y. in age; the crust from which the anomalies originate is thought to be the "trapped" Kula plate, which formerly collided with eastern Siberia and the eastern Bering Sea margin during the Mesozoic.

M. S. Marlow and D. W. Scholl, utilizing reconnaissance geophysical surveys of the eastern Bering Sea margin, recognized geologic basins and three geologic ridges beneath the shelf. The Mesozoic foldbelt of southern Alaska has been traced from the Alaska Peninsula through the shelf to eastern Siberia. Beneath the shelf, two of the largest basins, Navarin and St. George, contain an estimated 8 to 10 km of Upper Cretaceous (?) and Cenozoic strata. The basin fill is extensionally deformed along the flanks of these grabens and half grabens by high-angle normal "growth-type" faults. Within the sedimentary section, there is a divergence or disconformity of probable Miocene age. This basinward-dipping divergence may represent a major change in sedimentation rates over the shelf as a result of a change in the drainage of the Yukon River from the Pacific to the Bering Sea. The basin fill and the thick sedimentary section beneath the shelf are immediate petroleum prospects.

COASTAL ENVIRONMENTAL STUDIES

Turnagain Arm

A. T. Ovenshine, S. R. Bartsch-Winkler, N. R. O'Brien, and D. E. Lawson have accumulated evidence that Turnagain Arm, a 70-km-long estuary near Anchorage, Alaska, is flood dominant with respect to its long-term sedimentation budget. The principal results leading to this conclusion are:

1. The sand that fills most of the arm includes significant quantities of mineral (andalusite, staurolite, garnet, biotite, muscovite, and chlorite) and rock (pumice and coal) fragments that could not have come from the bedrock surrounding Turnagain Arm. These probably were derived from the drainage basin of the Susitna River and have been transported by tidal currents across Knik Arm and the upper Cook Inlet into Turnagain Arm.
2. Clast size and imbrication directions of gravel exposed on Girdwood Bar in 1974 indicate the predominance of eastward transport toward the head of the arm.
3. A transgressive deposit of intertidal sediment has formed at Portage in response to subsidence caused by the Alaskan earthquake of March 27, 1964. Mineral and rock fragments in the deposit indicate that its source was seaward in Turnagain Arm and not in the streams that flow from the surrounding mountains into the Portage area.

The flood-dominant character is environmentally significant in wetland management in the upper Cook Inlet area; there seems to be a high probability that a portion of any solid or liquid wastes discharged into Cook Inlet near Anchorage would be driven by tidal currents into Turnagain Arm.

SHELF ENVIRONMENTAL STUDIES

Beaufort Sea

Erk Reimnitz and P. W. Barnes utilized LANDSAT–1 and NOAA satellite imagery to make a seasonal study of the shear zone between the shore fast ice covering the inner shelf and the pack ice on the Arctic Ocean. The midwinter shear line marks the seaward boundary of the relatively undisturbed fast ice and forms between the 10- and 20-m depth contours along the northern coast of Alaska; its location

appears to be controlled by bathymetry and coastal configuration. The intensely deformed "shear zone" forms seaward of this shear line and contains a dense pattern of major pressure ridges. This shear zone intermittently shifts position when the ice moves westward at approximately 5 km/d. Major pressure ridges form during such movements, and their keels may extend to the sea floor and plough the bottom. Eventually, the pressure ridges become so firmly grounded that the ice in the shear zone resists further deformation; these winter conditions cause (1) a seaward extension of the fast ice up to 20 to 25 km along relatively straight stretches of coastline and (2) formation of new shear lines further seaward. Monitoring several periods of ice deformation shows that the ice along the active shear line is moving at similar or even faster rates than the ice seaward of the Continental Shelf. Ice within the 20- to 25-km-wide zone remains in place well into the period of general sea-ice breakup during the following summer, apparently because of the existence of firmly grounded pressure ridges in this zone.

Bottom surveys made after the sea-ice breakup delineate (1) a dense pattern of sea-floor gouges produced by ice in the zone of major pressure ridges on the central shelf and (2) a remarkably smooth bottom landward of the midwinter shear line (Reimnitz and Barnes, 1974). Box cores from the shear zone show that sediments are intensely mixed (Barnes and Reimnitz, 1974).

Close inshore, the seasonal fast ice at the end of the winter is relatively undisturbed, even where it comes in contact with the beaches. After ice melt, the beach face shows little evidence of ice deformation, except at shoreline promontories. Because the energy of sea-floor processes is concentrated seaward of 10 m depth, and not within the surf zone as it is on lower latitude shelves, offshore construction and shipping face formidable environmental problems off the northern coast of Alaska.

Barnes and Reimnitz found that rivers flood prior to the melting and breakup of the sea ice along the Beaufort Sea coast of Alaska. This flooding causes a freshwater overflow (1 m or more in depth) onto the sea ice in the vicinity of river mouths. The floodwaters carry very little sediment because the initial melting involves only the snow overlying the frozen soils and sediments. As the water drains through strudel in the ice canopy offshore, the bottom is extensively scoured. As the season progresses, the ice immediately offshore from the deltas melts owing to the influx of warmer river waters. Very little of this freshwater is mixed with the seawater, and a large freshwater reservoir results. The weak ocean currents, the small tidal range, and the presence of the ice cover nearby reduce mixing.

Examination of LANDSAT imagery indicates that the rivers of the North Slope overflow in sequence from southeast to northwest, apparently in response to the variance of solar insolation at different latitudes. Flooding of the sea ice by the Sagavanirktok River apparently began May 23, 1973, and still had not reached its maximum extent 5 d later. During the period of LANDSAT observation, the area of inundated sea ice increased from approximately 18 to 43 km^2. If the area were covered to an average depth of 0.75 m, this volume would represent a freshwater lake on the sea ice of at least 32×10^6 m^3, disregarding drainage and subsequent river flow.

Chukchi Sea

Side-scan sonar and high-resolution seismic profiling equipment together with underway sampling were used by Arthur Grantz to detail morphology and associated sediment types in the eastern Chukchi Sea. Detailed survey tracks were made around Cape Lisburne, between Point Franklin and Point Barrow, and along the northwestern perimeter of a newly discovered grounded ice mass approximately 180 km northwest of Point Barrow. Along each track line, sediment samples were collected by using grabs, gravity cores, and underway samplers. The sedimentological data were then correlated with sonographs taken over the sample site. The sonographs revealed extensive regions of ice scouring that was associated frequently with sand-wave ribbons or fields. Large sand-wave fields, apparent current furrows, and localized sharp sediment boundaries also were observed.

Bering Sea

C. H. Nelson found that Holocene sediments from the Yukon River form thin deposits (tens of centimetres) in parts of central Norton Sound and form thick deposits (several metres) off the present subdelta and around the margins of Norton Sound. These deposits typically contain thin horizons of shells and pebbles and also thin sand interbeds that are flat laminated, low-angle cross laminated, and ripple marked. The coarser grained interbeds are interpreted to be lag deposits of storm waves and associated storm-surge currents that have reworked the shallow sea floor of Norton Sound ($\leq$20 m deep) and have carried the finer grained resuspended sediment northward from the Bering Sea.

Well-preserved sedimentary structures are present only in the shallowest water near the fringe of the present Yukon subdelta; there the frequency of formation of lag deposits is greatest, and low salinity may inhibit benthic faunal activity. Elsewhere in the northeastern Bering Sea, bioturbation has destroyed most wave- and current-formed sedimentary structures.

The distribution of sediments off western Alaska has important implications for the interpretation of ancient epicontinental shelf sediments. Some parts of an epicontinental shelf—for example, Bristol Bay—may exhibit classical gradation from coarse to fine deposits offshore. Other parts, like the Chirikov basin, may display a complex mosaic of gravel, sand, and mud lenses unrelated to shoreline sources. Sediment thickness, like sediment grain size, may show no relation to source. Thick accumulations of Holocene sediment, apparently from the Yukon River, cover extensive areas of the Chukchi Sea north of nondepositional areas in the Bering Sea; only thin accumulations occur in some places close to the present delta. Transgressive sand and gravel layers may be extremely thin over large regions like margins of the Chirikov basin. Offshore epicontinental shelf sediments in a low-energy region like the northern Bering Sea may lack preserved physical sedimentary structures, except in areas where unusual conditions inhibit faunal activity.

Gulf of Alaska

Study of high-resolution seismic profiles in the northeastern Gulf of Alaska by B. F. Molnia and P. R. Carlson indicated that at least four distinct sediment types are exposed on the sea floor: (1) Undeformed Holocene sediments, (2) deformed Holocene sediments, (3) Quaternary morainal materials, and (4) tilted, folded, and lithified Tertiary and Pleistocene deposits. The stratigraphic relation between the four sediment types varies from locality to locality; not all types are present in each area. The ages of the four types are unknown and may vary over the study area.

Tertiary or Pleistocene deposits that may be the Yakataga, Poul Creek, or Katalla Formations crop out on Tarr Bank, the Middleton Island and Kayak Island platforms, and the Pamplona Sea Ridge and in the area south of Yakataga. Morainal materials compose the surficial sediment near Yakutat Bay, Icy Bay, and Bering Glacier. Holocene sediments mantle the remainder of the shelf area, the maximum sediment thickness approaching 300 m near the Copper River; these thick deposits commonly show slump structures that may be seismically induced.

West of Kayak Island, the Copper River is the primary source of Holocene sediment. Interpretation of seismic profiles and LANDSAT imagery indicates that Copper River sediment is supplied to Prince William Sound through the Hinchinbrook entrance, the Hawkins Island Cutoff, and the Orca Inlet and spreads eastward toward Controller Bay. In addition, some Copper River sediment bypasses Tarr Bank and is deposited on the Outer Continental Shelf. East of Kayak Island, the major sediment sources are streams draining the larger ice fields, notably the Malaspina and Bering Glaciers. Transport of bottom and suspended sediment is predominantly westward.

GENERAL OCEANIC AND INTERNATIONAL STUDIES

Project FAMOUS

For the French-American Mid-Ocean Undersea Study (FAMOUS), J. G. Moore participated in 6 of 13 dives made by the submerisble *Alvin* to the rift-valley floor of the Mid-Atlantic Ridge at 36° N. Project FAMOUS also included dives by the French submersibles *Archimede* and *Cyana*. The typical dive was to a depth of 2600 to 2800 m, traversed a distance of 700 m on the bottom, occupied four stations where rock, water, and sediment samples were taken, and took several hundred photographs from external and internal cameras. Studies made from the submersibles showed that the rift-valley floor is extremely rugged. Collection and mapping of pillowed basaltic lava flows suggested that the age of the lava appeared to increase systematically outward from a 1-km-wide zone at the rift-valley axis. The entire rift-valley floor is cut by a system of cracks and faults that are about parallel to the axis and that increase in width and throw outwards. The width of the cracks ranges from a few centimetres to 10 m.

Deep Sea Drilling Program

M. A. Lanphere and G. B. Dalrymple determined K-Ar ages on basalts from three Pacific Ocean sites drilled on legs 33 and 34 of the DSDP. The age of crystallization of basalt is 91.2 ± 2.7 m.y. in hole 315A from the Fanning Island volcanic edifice in the Line Islands. Previously, scientists from leg 33 suggested that paleontologic evidence and sedimentation-rate extrapolation for sites 315 and 316 indicate that volcanism ceased at about the same time between 79 and 85 m.y. ago at all three sites. They thus concluded that the Line Islands were approxi-

mately coeval and were not formed by movement of the Pacific plate over a mantle "hotspot." Lanphere and Dalrymple believe that only the volcanism at site 315 is precisely dated. The basalt at the bottom of hole 165 has not been dated; because of poor core recovery and uncertainty in the location of fossil zones within the core, the age of basalt based on sedimentation-rate extrapolation is ambiguous. The minimum age of the basalt basement in hole 165 could be greater than 100 m.y. Basalt was not reached in hole 136, but Campanian volcanogenic sediments, which occur at the bottom of the hole, suggest a minimum age of 81 to 83 m.y. for cessation of volcanism. Thus, there is no evidence at this time that the Line Islands do not become younger from north to south, and the melting spot hypothesis must be retained as a viable working hypothesis for the origin of this linear volcanic feature.

The minimum age of the basalt basement in hole 317A, leg 33, from the Manihiki Plateau is 106.0 ± 3.5 m.y., and the estimated crystallization age, based on the relative degree of alteration of whole-rock samples, is approximately 110 to 120 m.y. This estimated age is in reasonable agreement with poorly preserved fossils recovered from sediments above the basalt basement from the Bauer deep, a depression between the active East Pacific Rise to the west and the inactive Galapagos Rise to the east.

A K-Ar age of $>13.0 \pm 1.5$ m.y. from hole 319A, leg 34, was measured on relatively fresh basalt. This age should be close to the age of crystallization. It agrees within analytical uncertainty with the age of 15 ± 1 m.y. for the Orbulina datum, which occurs a few metres above the sediment-basalt contact, and with the age of the crust inferred from sea-floor spreading rates.

Peru-Ecuador deep-sea biostratigraphy

Pliocene and Quaternary phytoplankton assemblages have been recovered by continuous coring at DSDP sites 157 (2° S.), 320 (9° S.), and 321 (12° S.), all about 350 km west of Ecuador and Peru, and beyond the coastal area of strong present-day upwelling. J. D. Bukry reported that paleoenvironmental indicator taxa in the phytoplankton assemblages show that the Quaternary water was warmer than the upper Pliocene water, and the upper Quaternary (Brunhes magnetic epoch) water was especially warm. The cocolith *Cocolithus pelagicus*, indicating cool water, is consistently present in the Pliocene but disappeared locally in the early Quaternary. The silicoflagellate genus *Distephanus*, indicating cool water, occurs in significant numbers (10 to 25 percent of the total population) only in the Pliocene. In Quaternary assemblages, which are dominated by the warm-water genus *Dictyocha*, *Distephanus* is absent or less than 5 percent. The lowest numbers of *Distephanus* are in the youngest silicoflagellate zone, the *Dictyocha epiodon* Zone, which is correlative with the Brunhes magnetic epoch (approximately 0.0 to 0.7 m.y.). The biogenic sedimentation rate in the Pliocene, which is higher than that in the Quaternary, at DSDP 157 probably indicates more nutrients and stronger upwelling, which also correlate with cooler surface water. This evidence suggests that Quaternary large-scale air-water circulation patterns related to glaciation nearer the poles are associated with less upwelling at these sites off northern South American than they were in the Pliocene.

Marine geology from Tahiti to Panama, equatorial Pacific

H. E. Cook found that North American stratigraphic principles, as developed by geologic mapping on continents, can be applied to deep-sea sediments. The ability of the DSDP to obtain long cored intervals at numerous ocean-basin sites can provide sufficient data for the definition and recognition of rock stratigraphic units (formations). Synthesis of these data into various types of maps and cross sections can help provide a stratigraphic and sedimentologic framework within which our interpretations must lie. This approach brings the Tertiary geologic history of the equatorial Pacific into better focus. This history is complex and is not adequately explained by a simple model of sedimentation in which deposition took place in progressively deeper water as seafloor spreading moved the sites westward.

Paleoequator reconstructions using chronostratigraphic isopachs support earlier hypotheses that, in the middle Tertiary, the north-northwestward migration of the Pacific plate took a more west-northwestward trend. Data in this study suggest that this change took place sometime in the early to middle Miocene (15 to 25 m.y. B.P.).

Marine geology of Line Islands, equatorial Pacific

H. E. Cook found that the postvolcanic stratigraphic succession along the Line Islands is divisible into five lithologically distinct units that can be correlated at least 1,200 km between JOIDES DSDP sites 165, 315, and 316. The uppermost two units are lithologically and stratigraphically correlative to the east with the Clipperton Oceanic Formation, which is recognized as far west as the East Pacific Rise.

Downhole induration changes (from ooze to chalk and from chalk to limestone) are not merely a function of burial depth. The degree of cementation in the ooze-chalk-limestone transition may depend more on initial sediment composition and time than on depth of burial. This independence of depth of burial and degree of chalkification is becoming better documented as more drilling is done in deep-sea sediments.

The following people contributed to the study of the marine geology of the Line Islands: H. E. Cook and E. D. Jackson (USGS), S. O. Schlanger (Univ. of California, Riverside), A. G. Kaneps, E. L. Winterer, and R. E. Boyce (Scripps Institution of Oceanography), H. C. Jenkyns (Univ. of Durham), D. A. Johnson (Woods Hole Oceanographic Institute), K. R. Kelts (Ecole Polytechnique Fédérale), E. Martini (Geologisch-Paläontologisches Institut), and C. L. McNulty (Univ. of Texas).

Results from the leg 33 "hotspot" cruise in the Line Islands and site 165 of leg 17 indicated that flow volcanism ceased on a 1,270-km-long segment of the chain between 79 and 85 m.y. B.P. The similarities of the postflow geological histories of all Line Island sites indicate the following: (1) early to middle Campanian volcanoclastic deposition, (2) Campanian to Maestrichtian reef buildups nearby, and (3) Oligocene emergence of atolls atop the ridge. No "hotspot" hypothesis that requires systematic movement of the Pacific plate over a fixed melting anomaly can account for the geochronology of Line Island volcanism. Site 318 on the Tuamotu Ridge revealed that volcanic edifices of the ridge had been built, eroded, and capped by reefs by early Eocene time 50 m.y. B.P. Consequently, the Tuamotu "elbow" is probably older than the Hawaii-Emperor "elbow," which was recently estimated to be approximately 42 m.y. old. A thick section of Cretaceous volcanogenic sediments on the Manihiki Plateau contained flecks of native copper and signs of hydrothermal alteration.

Submarine sediment gravity flows.—H. E. Cook (USGS), H. C. Jenkyns (Univ. of Durham), and K. R. Kelts (Geological Institute, Zurich) discovered during coring on leg 33 of the DSDP a wide variety of Cretaceous to Quaternary submarine sediment gravity-flow deposits along the Line Islands. At certain stratigraphic intervals, these allochthonous deposits comprised up to 50 percent or more of the section. Texturally, they ranged from beds composed of silt-sized grains to breccias with clasts up to 2×5 cm in cross section. The sand-sized debris exhibits a number of primary sedimentary structures, whereas the breccias are massive and often devoid of any internal structures. These sediments, which contain pelagic, volcaniclastic, and shoal-water reefal debris, were derived from three major sources: shallow-marine carbonate complexes along the Line Islands, volcanic terranes in shallow and (or) deeper water, and basinal deep-marine environments. Various mechanisms were probably involved during their transport and deposition. These possibly included a spectrum from viscous, turbulent motion for the graded and laminated sands to plasticoviscous motion (Coulomb viscous or Bingham) of a debris flow type for the massively bedded mud-rich breccias.

Diagenesis of limestone.—H. E. Cook found that, during leg 33 of the DSDP, a 30-m-thick porous dolomite sequence was cored in deep-sea sediments along the Line Islands. In this area, the deep-marine sediments are up to 1,000 m thick and range in age from Santonian to Holocene. They consist of nannofossil-foraminiferal oozes, chalks, and limestones with liberally interspersed sediment gravity-flow deposits derived from upslope basinal and shallow-water carbonate environments. The dolomite occurs 450 m below the sea floor in Eocene sediments, yet well above the Santonian basaltic basement at 900 m. Its textural characteristics and stratigraphic position strongly suggest that it represents a dolomitized deep-marine limestone. Details of its origin are not yet known. Under the proper geologic setting, porous dolomitized deep-marine sediments could form petroleum reservoirs.

ESTUARINE AND COASTAL HYDROLOGY

ATLANTIC COAST

Preliminary analyses by F. A. Johnson of the Edisto and Ashepoo estuaries in South Carolina indicated vertically well-mixed conditions at high slack tide. Saltwater was detected about 11 km farther upstream in the Ashepoo than in the Edisto because of lower flow in the Ashepoo. This effect is expected to be more pronounced during drought conditions. Selected samples indicated good-quality water in both estuaries; no pesticides were detected in the water column, and very little was found in the bottom sediments.

R. L. Cory and J. M. Redding (R. L. Cory, J. M. Redding, and M. M. McCullough, 1974) completed data summaries of 4 yr of physical, chemical, and biological studies in the Rhode River estuary on the

western side of the Chesapeake Bay in Anne Arundel County, Md. At a monitor station, water at the 1-m level ranged from 0.7° to 32.6°C, salinity ranged from 1.05 to 14.03 ppt, turbidity ranged from 5 to 80 JTU, DO ranged from 0 to 19.8 mg/l, and pH ranged from 6.8 to 10.1. The maximum water-level range was 1.8 m, with a mean tide range of 0.5 m.

Daily estimates of net plant production and night respiration of oxygen were made for an entire year by using DO, temperature, and salinity data from the monitor station. Net oxygen production ranged from 0.1 to 8.6 g m^{-3} d^{-1}, and nighttime oxygen respiration ranged from 0.1 to 8.2 g m^{-3} d^{-1}. Mean monthly values of both ranged from a February low of 0.4 to an August high of 4.5 g m^{-3} d^{-1}; there was no evidence of spring or autumn pulses. Day-to-day variations of both values were large, and a summation of the entire year's data indicated a balanced system with a net production equal to night respiration.

The average of the daily pH range at the monitor station for the month of August in the years 1971, 1972, 1973, and 1974 shows the effects of Hurricane Agnes (1972) runoff. Values are 0.90, 1.42, 1.00, and 0.98 pH units, respectively; it appears that the Chesapeake Bay's metabolism decreased after reaching 1.42 in 1972.

GULF COAST

The flow of the Vermilion River in southwestern Louisiana is affected by lunar and (or) wind tides as far upstream as Lafayette, La. (about 72 km upstream from the Gulf of Mexico), according to L. D. Fayard. Data from dye-tracer tests made during a low-flow period showed no net downstream water movement during two consecutive tide cycles. The river cannot assimilate biodegradable wastes during low-flow periods, and DO levels range from 2.0 to 4.0 mg/l during summer and early fall.

G. E. Seaburn and M. E. Jennings used a steady-state digital water-quality model to assist the Florida Department of Pollution Control in making waste-load allocation analyses of several small estuaries on the Florida gulf coast. In applying the model to the analysis of DO, they learned that photosynthesis and respiration by submerged aquatic plants in Crystal River, a spring-fed estuary, are major factors in the oxygen balance of the estuary. In areas of dense submerged plants, DO ranged from less than 3 to more than 10 mg/l over a 24-h period.

C. R. Goodwin reported that detailed bottom contours of Tampa Bay, Fla., compiled from hydrographic and photogrammetric data, are being included on revised topographic quadrangle sheets of the area. The new maps are experimental and not intended for navigational purposes. They will be of value for engineering, scientific, and recreational purposes.

Results of Goodwin's two-dimensional digital simulation modeling of the hydrodynamics of Tampa Bay have been used by the Corps of Engineers to help define the effects of the proposed deepening of the main ship channel. A recent study showed that a few large elongated islands constructed from dredged material are more effective for inducing beneficial circulation in the bay than many smaller islands; flow can be directed and controlled to a much greater degree with larger islands.

Goodwin's proposal to place a one-way tide gate on an existing culvert in a causeway in Old Tampa Bay, Fla., may result in significant water-quality improvement in the region at savings of well over $0.5 million. A previous plan called for construction of a four-lane bridge with a 100-m span. Tests, made in conjunction with the Florida Department of Transportation, showed that 0.34×10^6 m^3/d of good-quality water could be induced to flow through the degraded region by installing a tide gate.

PACIFIC COAST

Parameters of a digital model, developed by W. L. Haushild and E. A. Prych, of the stratified Duwamish River estuary in Washington include effects due to flow, transport, and individual parameters and constituents such as salinity, temperature, phytoplankton, BOD, and DO. Model results give phytoplankton growth rates and peak concentrations that agree with those reported in the literature. The model predicts a maximum decrease of 2 mg/l in the average monthly DO concentration if the discharge of secondary treated wastes increases from the 1971 level of 1.05 m^3/s to an anticipated rate of 6.31 m^3/s. Other study findings show that nutrient concentrations in the estuary are high enough not to limit growth of *Cyclotella* sp. or oval flagellates, the summer "bloom" phytoplankton. Also, the net primary productivity of periphyton responds to changes in environmental conditions and nutrient concentrations between the mountainous, valley, and estuarine reaches of the Green and Duwamish Rivers.

Seasonal changes in the relative influence of sediment-transport mechanisms were observed by J. L. Glenn in the intertidal environments of three estu-

aries along the Oregon coast. Major changes in transport mechanisms were related to seasonally varying wave climate, tides, and river flows, but other mechanisms were locally important and also varied seasonally. During the relatively dry summer months, sand transport by flotation was widespread; this mechanism was particularly effective where burrowing organisms produced accumulations of sediments that protruded above the general level of the surrounding tide flat. Generally, materials transported by flotation moved toward higher parts of tide flats. Rain splash and sheet runoff were the dominant transport mechanisms associated with hard winter rains. These resulted in offshore sediment movement on tide flats located around the estuary margins. On midestuary flats, rain splash and sheet runoff resulted in sediment movements from high areas to adjacent low areas. High winter ground-water levels in supratidal deposits caused extensive seepage and rill development across adjacent exposed tidal flats. Although little sediment was observed moving in these rills, the presence of the rills indicates that erosion and offshore sediment movements had occurred.

The effect of salinity variations on exchangeable cations in suspended sediment from the Mattole River and estuary in California was investigated by V. C. Kennedy and R. J. Avanzino. They found that magnesium reached a maximum percentage of the exchangeable cations at about 3 ppt salinity and then decreased with further increase in salinity. Sodium, however, increased steadily with increasing salinity. These results do not agree with other results given in the literature because of differences in the methods used for eliminating the effects of interstitial saline water. Kennedy and Avanzino applied an interstitial water correction to the concentrations of exchangeable cations found in the desorbing solution, whereas other investigators washed off saline water with distilled water before desorbing and thus shifted the adsorbed cation ratio before the desorption step. The result is that relatively high magnesium and low sodium contents have been previously reported as exchangeable cations on marine sediments. The study by Kennedy and Avanzino shows the reverse to be true.

MANAGEMENT OF NATURAL RESOURCES ON FEDERAL AND INDIAN LANDS

The Conservation Division is responsible for carrying out the USGS's role in the management of the mineral and water resources on Federal and Indian lands, including the Outer Continental Shelf; that role includes, in particular, the conservation, evaluation, and development of the leasable mineral resources and waterpower potential of these areas. Primary functions are (1) mapping and evaluation of mineral lands, (2) delineation and preservation of potential public-land reservoir and waterpower sites, (3) promotion of orderly development, conservation, and proper utilization of mineral resources on Federal lands under lease, (4) supervision of mineral operations in a manner that will assure protection of the environment and the realization of a fair value from the sale of leases and that will obtain satisfactory royalties on mineral production, and (5) cooperation with other agencies in the management of Federal mineral and water resources.

CLASSIFICATION AND EVALUATION OF MINERAL LANDS

The organic act creating the USGS gave the Director the responsibility of classifying and evaluating the mineral resources of public-domain lands. There are about 101 million hectares of land for which estimates of the magnitude of leasable mineral occurrences have been only partly made. Such appraisals are needed to reserve valuable minerals in the event of surface disposal and to assist in determining the extent of our mineral resources. Estimates are based on data acquired through field mapping and the study of available geologic reports in addition to spot checks and investigations made in response to the needs of other Government agencies. As an aid in this assessment of certain minerals, guidelines have been prepared setting forth limits of thickness, quality, depth, and extent of a mineral occurrence that are necessary before land is considered to be mineral land.

Classified land

As a result of USGS investigations, large areas of Federal land have been formally classified "mineral land." Mineral-land classification complements the leasing provisions of the several mineral-leasing laws by reserving to the Government, in disposals of public land, the title to such energy resources as coal, oil, gas, oil shale, asphalt, and bituminous rock and such fertilizer and industrial minerals as phosphate, potash, sodium minerals, and sulfur.

These reserved minerals on public lands are subject to development by private industry under the provisions of the Mineral Leasing Act of 1920. All minerals in acquired lands and on the Outer Continental Shelf are subject to development under comparable acts.

Known Geological Structures (KGS) of producing oil and gas fields

By the provisions of the Mineral Leasing Act of 1920, the Secretary of the Interior is authorized to grant to any applicant qualified under the act a noncompetitive lease to prospect for oil and gas on any part of the mineral estate of the United States that is not within any KGS of a producing oil or gas field. Lands within such known structures are competitively leased to the highest bidder. During fiscal year 1975, over 94,344 ha of onshore Federal land were determined to be in KGS's.

Known Geothermal Resources Areas (KGRA)

The Geothermal Steam Act of 1970 provides for development by private industry of federally owned geothermal resources through competitive and noncompetitive leasing. During fiscal year 1975, 101,803 ha were included in KGRA's, and 9,234 ha were classified as valuable prospectively for geothermal resources.

A total of $5,588,924 was received for 66,887 ha leased through competitive bidding in 15 lease sales. During fiscal year 1975, 53 noncompetitive leases totaling 36,520 ha were issued.

Known leasing areas for coal and potassium

During fiscal year 1975, six Known Coal Leasing Areas (KCLA) totaling 580,956 ha were defined in North Dakota, Utah, and Wyoming. An addition of 26,981 ha was made to the known potash leasing area in New Mexico.

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 that have significant potential for future development. Such sites are an increasingly scarce and valuable natural resource. USGS engineers study maps, photographs, and waterflow records to discover potential damsites and reservoirs. Topographic, engineering, and geologic studies are made of selected sites to determine if the potential value is sufficient to warrant formal classification of any Federal land within the site. 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, and, if the land is no longer considered suitable for reservoir development, it is released for return to the unencumbered public domain for other possible disposition. During fiscal year 1975, about 17,000 ha of previously classified lands were released, and the review program was carried on in 10 river basins in the Western States and Alaska.

There is an increasing trend toward the development of pumped-storage hydroelectric projects. By using reversible equipment that can serve for both pumping and generating, these developments usually provide peaking capacity at a relatively low unit construction cost. During fiscal year 1975, USGS engineers conducted studies on several of the most favorable pumped-storage sites affecting Federal lands in Idaho and Oregon.

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 USGS, under delegation from the Secretary of the Interior. It includes (1) geologic and engineering examination of applied-for lands to determine whether a lease or a permit is appropriately applicable, (2) approval of operating plans, (3) inspection of operations to insure compliance with regulations and approved methods, and (4) verification of production and the collection of royalties. (See table 2.)

Before recommending a lease or permit, USGS engineers and geologists consider its possible effects upon the environment. Of major concern are the esthetic value of scenic and historic sites, the preservation of fish and wildlife and their breeding areas, and the prevention of land erosion, flooding, air pollution, and the release of toxic chemicals and dangerous materials. Consideration is also given to the amount and kind of mining-land reclamation that will be required.

Louisiana and Texas Outer Continental Shelf lease sales for oil and gas

Four sales of Federal Outer Continental Shelf leases for oil and gas were held in fiscal year 1975. In sales held in July 1974, October 1974, February 1975, and May 1975, 1,353 tracts comprising 2,807,390 ha were offered for lease. High bids totaling $1,966,099,135 were accepted for 732,438 ha in 326 tracts. USGS geologists, geophysicists, and engineers evaluated each tract offered to insure receipt of fair market value to the Government.

COOPERATION WITH OTHER FEDERAL AGENCIES

The USGS acts as a consultant to other Federal agencies in land-disposal cases. In response to their

TABLE 2.—*Mineral production, value, and royalty for fiscal year 1975* [1]

Lands	Oil (tonnes)	Gas (thousand cubic metres)	Gas liquids (litres)	Other [2] (tonnes)	Value (dollars)	Royalty (dollars)
Public	22,688,000	30,449,000	1,939,637,000	41,833,000	$1,855,600,000	$196,945,000
Acquired	827,000	875,000	14,054,000	685,000	186,671,000	11,755,000
Indian	4,128,000	3,405,000	203,274,000	21,128,000	332,054,000	41,761,000
Military	47,000	666,000	81,964,000	--------	11,548,000	1,852,000
Outer Continental Shelf	46,156,000	92,686,000	7,839,425,000	1,426,000	3,546,667,000	553,037,000
Naval Petroleum Reserve No. 2	272,000	110,000	52,354,000	--------	14,619,000	1,691,000
Total	74,118,000	128,191,000	10,130,708,000	65,072,000	5,947,159,000	807,041,000

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

requests, determinations are made as to the mineral character and water-resource development potential of specific tracts of Federal lands under their supervision that are proposed for sale, exchange, or other disposal. About 15,000 such reports were made during fiscal year 1975.

GEOLOGIC AND HYDROLOGIC PRINCIPLES, PROCESSES, AND TECHNIQUES

EXPERIMENTAL GEOPHYSICS

HEAT FLOW

Geothermal setting of Long Valley caldera

Heat-flow and heat-production measurements have been made by A. H. Lachenbruch, J. H. Sass, R. J. Munroe, and T. H. Moses, Jr., in the vicinity of Long Valley 0 to 30 km from the rim of the caldera and up to 30 km on either side of the boundary of the Basin and Range province at the eastern scarp of the Sierra Nevada. The data show no conspicuous effect of the province transition, possibly a small local heat-flow anomaly near the caldera's eastern rim and a very substantial anomaly near the western rim. Simple heat-conduction models suggest that Long Valley caldera is the surface expression of a deep magmatic system; an upper crustal magma chamber probably could not have sustained molten material throughout the 2-m.y. eruptive history unless it was resupplied with heat from deep crustal magmatic sources. Thermal models for the near-normal heat flow at the eastern rim justify speculation that magma beneath the eastern part of the caldera was exhausted during the eruption of the Bishop Tuff 0.7 m.y. ago and that the resurgent dome, which subsequently formed in the west-central caldera, marks the location of a residual chamber more circular in plan. High heat flow indicated by the single measurement near the western rim can be attributed to a simple shallow magma chamber beneath the western caldera or to recent local magmatism along the Sierra frontal fault system.

Near-surface hydrothermal regime of Long Valley caldera

Temperature measurements in 29 shallow holes (~30 m) drilled by R. E. Lewis in Long Valley caldera were interpreted by A. H. Lachenbruch, M. L. Sorey, R. E. Lewis, and J. H. Sass. Temperatures at 5- to 10-m depths can be contoured systematically; they correlate well with the character of the thermal gradient to 30 m. Where the temperature at a depth of 10 m is less than 11°C (group I), the gradients to 30 m are practically zero; where the 10-m temperature is between 11° and 16°C (group II), the gradients are 200° to 400°C/km and uniform, corresponding to conductive heat flows of 4 to 8 HFU. Where the 10-m temperatures exceed 16°C (group III), gradients are larger and irregular with local heat flows to 50 HFU. Thermal considerations suggest that the first group represents hydrologic recharge, the second group a conductive regime to substantial depth, and the third group hydrologic discharge. This interpretation is supported by limited drilling to depths up to 300 m. Regimes in the first group in the peripheral part of the caldera suggest that it is an area of recharge. The hot springs discharge in a fault zone characterized by near-surface regimes in groups II and III; chemical evidence indicates that their source temperature is about 200°C. Evidently, the springs are fed by local fractures; if the background regime is conductive, their source is probably less than 1 km deep. Hydrologic and isotopic data indicate that gross circulation in the hydrothermal system is from west to east and suggest that the hot springs gain their heat in the western part of the caldera. The large amount of heat presently being removed from the caldera by flowing water and the inference that hydrothermal activity was more intense in the past support the view that Long Valley has been resupplied frequently with heat from deep magmatic sources throughout its eruptive history.

Heat flow at The Geysers, California

T. C. Urban (USGS), I. M. Jamieson (Pacific Energy Corporation), and W. H. Diment and J. H. Sass (USGS) (1975) have analyzed temperature profiles in three cased holes close to thermal equilibrium over a known part of The Geysers steam field and in one hole near Cloverdale some 13 km to the west. The linearity of the temperature curves to the maximum depths examined (200 to 1000 m) suggests conductive transport of heat. Moreover, linear extrapolation of these temperatures to the depth of "first steam" (where known) yields a temperature close

to that of the steam reservoir, which is generally regarded as about 240°C. It is thus suggested that heat transport is mainly conductive through the whole interval between the surface and the reservoir, at least at this locality. It is also suggested that the reservoir temperature has remained relatively constant for thousands of years. Heat flows of greater than 3 μcal/cm^2 s for Cloverdale and 9, 11, and 12 μcal/cm^2 s for the three holes over the known portion of the field were estimated. Elementary calculations show that the conductive heat removal in and about the field is very small relative to that of present steam production but that energy stored above ambient temperature is large with respect to annual steam production.

Heat flow on the southern flank of the Snake River rift

Rifting in southern Idaho has been active for some time. Holocene volcanism, abundant hot springs, and hot-water wells attest to an anomalous geothermal regime. Preliminary heat flows obtained in this region by T. C. Urban and W. H. Diment (1975) are as high or higher than most in the Basin and Range province to the south. The "reduced" heat flows (those obtained after allowance is made for the radioactive heat production of the igneous rocks) also are high with respect to those in the Basin and Range. The highest values are from holes in the Raft River valley, and they probably reflect hydrothermal convection at depth.

Convective heat flow at Yellowstone National Park

The estimated heat discharged by chloride-rich thermal waters east of the Continental Divide in Yellowstone National Park was reevaluated by R. O. Fournier, D. E. White, and A. H. Truesdell by means of a chloride inventory method. Flow rates and chloride contents of rivers draining regions of hot-spring activity were measured, and chloride contents and temperatures of deep hot-water aquifers were calculated by using compositions of spring waters. This information provided estimates of the volume of hot-spring water reaching the rivers and the original heat content before adiabatic and conductive cooling. The heat discharged by spring water above 4°C (the mean annual temperature) in the Madison River drainage is 6.4×10^8 cal/s and in the Yellowstone River drainage is 4.0×10^8 cal/s. The Upper, Midway, Lower, and Norris Geyser basins discharge into the Madison River drainage. West Thumb, Mud Volcano, and Mammoth basins discharge into the Yellowstone River drainage. The convective heat flow due to thermal waters within the portion of the Yellowstone caldera draining to the east of the Continental Divide (2,313 km^2) is 9.3×10^8 cal/s, and the average heat flux is 40 μcal/cm^2 s.

Oxygen-18 in chert as an indicator of ancient geothermal gradients

Irving Friedman analyzed oxygen-isotope abundances in diatoms and various forms of chert collected by K. J. Murata from Miocene rocks of the Temblor Range, Calif. The analyses suggest that the diatoms grew at 21° to 28°C, the cristobalitic chert formed at about 45°C, and the quartzitic chert formed at 80°C. These temperatures can be translated into geothermal gradients and indicate a lower heat flow in the Miocene in the Temblor Range (0.75 μcal/cm^2 s) compared to the present value of 1.3. Similar analyses of cherts from the Monterey Shale in the Taft area show that the Miocene geothermal gradient was normal (heat flow$\sim$1.2 μcal/cm^2 s) in that area.

ROCK MAGNETISM

Paleomagnetic intensities of subaerial and submarine basalts

S. C. Grommé (USGS) and Michel Prévot (Univ. of Paris) (1975) compiled measurements of the intensity of remanent magnetization for 177 subaerial basalt flows ranging in age from historic time to 10 m.y. and for 204 submarine basalt samples from the North Atlantic basement. No significant difference in mean intensity is observed between subaerial basalts younger than 700,000 yr and older, normally magnetized basalts, and, after partial demagnetization in 200 Oe, no difference is seen between historic basalts and older basalts of either polarity. Grommé and Prévot conclude that (1) no significant decay in the intensity of remanent magnetization in subaerial basalt occurs for several million years after eruption and (2) no large increase of the geomagnetic field intensity occurred during the Brunhes normal polarity epoch and, hence, such an increase cannot be the cause of the larger amplitude of the axial magnetic anomaly over midocean ridges. For oceanic basalts, the mean intensity of magnetization decreases by about two-thirds from the bottom of the median valley to the flanks of the ridge. This diminution is comparable to the parallel decrease in amplitude of magnetic anomalies and results from low-temperature oxidation of titanomagnetite.

Magnetism in deep-sea basalts of the Nazca plate, eastern Pacific Ocean

Magnetic properties of basaltic basement rocks from the Nazca plate that were obtained on leg 34 of

the DSDP were investigated by S. C. Grommé and E. A. Mankinen. Paleomagnetic inclinations measured in the drill cores indicate that no detectable change in the latitude of the Nazca plate has occurred since late Eocene time. Evidence of moderate to extreme low-temperature oxidation of titanomagnetite to titanomaghemite was found in all samples. This oxidation has not affected most of the paleomagnetic directions but in one case has proceeded far enough to cause a self-reversal of natural remanent magnetization. Oxidation has markedly reduced the intensity of magnetization and the susceptibility but appears to have increased the coercivity of remanent magnetization. An improved method of alternating-field demagnetization has been found necessary to remove secondary magnetizations acquired by these rocks during the drilling operations.

Paleomagnetic dating of Pleistocene lava flows, Grand Canyon, Arizona

Upper Pleistocene lava flows have dammed the Colorado River in the lower Grand Canyon, Ariz., on two or more occasions. Paleomagnetic measurements made by S. C. Grommé and E. A. Mankinen on 32 erosional remnants of these basalts show normal polarity, which indicates that the formation of the lava dams and their subsequent breachings all occurred within the last 950,000 yr and most probably within the last 700,000 yr. The two main groups of natural magnetization directions that are observed may represent two main pulses of eruptive activity because the same shift in direction occurs in two separate stratigraphic sections and corresponds approximately to a known erosional interval.

Analysis of paleolatitudes and paleomagnetic inclinations in the northwestern Pacific area

A method of analysis was developed by A. V. Cox for obtaining correct paleolatitudes from paleomagnetic inclinations that are measured in azimuthally unoriented vertical drill cores. The correction factor, derived from probability arguments and added to the apparent paleolatitude to obtain the true one, ranges from 13° at 71° latitude to zero at the equator. Confidence limits for paleolatitudes have been derived from an empirical model for paleosecular variation. The correctness of the paleolatitude correction and of the confidence limits has been confirmed by comparing them with Quaternary paleomagnetic data from Nunivak and the Pribilof Islands, Alaska. This method of analysis has also been applied to paleomagnetic inclinations measured in cores of Cretaceous basaltic basement obtained by the DSDP from the Pacific plate. The inclinations have been combined to give a paleomagnetic pole that is very close to the one obtained by earlier workers, who used magnetic anomaly data over Cretaceous seamounts in the Pacific.

Precambrian magnetic reversals and polar wandering: application to geologic correlations between Arizona and Montana

The geomagnetic polarity chronology recorded in the Unkar Group and overlying Nankoweap Formation of the Precambrian Grand Canyon Supergroup in northern Arizona was found by D. P. Elston to consist of a very long interval of normal polarity followed by at least five brief periods of reversed polarity. Preliminary results indicate a similar pattern in much of the Precambrian Belt Supergroup of Montana. The onsets of reversals in these two sedimentary rock sequences apparently represent the same point in time, a point that is also broadly indicated by the results of radiometric dating. This correlation means that the middle part of the Snowslip Formation of the Missoula Group of the Belt Supergroup is equivalent to the upper middle part of the Dox Sandstone of the Unkar Group. Most of the preliminary polar wandering path obtained from the Belt Supergroup does not coincide with the established polar wandering path for the Grand Canyon Supergroup. Points on the two paths corresponding to a time of 1,100 m.y. ago are 30° of arc apart. This discordance suggests that the Belt Supergroup was transported to its present position relative to the Arizona Precambrian rocks some time in latest Precambrian or earliest Paleozoic time.

Reversed magnetic polarity in lavas from Antarctica

Lava cores recovered from two boreholes in the McMurdo Volcanics of Antarctica by the Dry Valley Drilling Project were investigated by H. R. Spall. All the lavas have reversed magnetic polarity, which indicates that they are older than 700,000 yr. A detailed study of one 44-m-thick lava flow has shown that it is magnetically very stable and that, when the lava was erupted, the paleointensity of the geomagnetic field was about 0.1 Oe, about one-fifth of its present value.

COMPUTER MODELING

Earthquake modeling

D. J. Andrews reported that, from computer models of earthquakes in seismic gaps, systematic relationships were found between the energy and moment of an earthquake and the parameters characterizing the initial state. From more detailed

models of the rupture front, it was found that energy must be absorbed for other components of shear stress to be finite.

W. D. Stuart proposed a model invoking extensive fault creep before earthquakes to explain transient geophysical phenomena observed before earthquakes. The model so far appears to be consistent not only with published observations but also with recent surface tilt anomalies associated with moderate earthquakes on the central San Andreas fault. The dilatancy fluid-diffusion hypothesis currently in fashion seems to be incompatible with the tilt data. Unlike the fluid-diffusion model, the premonitory creep model suggests that substantial slip on the fault plane near the focal region occurs before the earthquake and is accompanied by decreasing shear stresses. In this construct, the earthquake plays a minor role in fault dynamics, although, of course, it causes the greatest cultural damage.

Resistivity interpretation

A. A. R. Zohdy developed the necessary formulas for the calculation of the various bipole-dipole apparent resistivity maps that will be obtained when a current bipole is placed near a vertical contact separating two homogeneous and isotropic media of different resistivities. The azimuth of the current bipole with respect to the strike of the surface trace of the vertical contact is variable. The problems where the current bipole is on one medium and where the bipole straddles the contact were both solved. A computer program for the bipole-dipole simple total-field apparent resistivity was written by R. J. Bisdorf. The calculation of such maps will be valuable in interpreting field surveys that have already been made in Long Valley and Hollister, Calif., Raft River valley and the Snake River Plain, Idaho, and other geothermal areas.

GEOMAGNETISM

Geomagnetic observatories

Recordings of the temporal variations in the three components of the Earth's magnetic field (horizontal intensity, vertical intensity, and direction) were made at a worldwide network of 12 geomagnetic observatories. Absolute field measurements are made every few days at each of the observatories to provide baseline control and to provide data for long-term geomagnetic secular change studies. Recordings and observations are disseminated to the world scientific community through the World Data Centers. J. D. Wood is responsible for the operation of the observatory network, and R. J. Main is responsible for data processing and quality control.

Repeat magnetic surveys

Measurements and recordings of absolute values and variations in the direction and in the horizontal and vertical intensities of the Earth's magnetic field are acquired at more than 200 repeat stations scattered throughout the conterminous United States, Alaska, and the Pacific islands. These data are primary input to the compilation of the U.S. and World Magnetic Charts and to magnetic secular change studies. Twenty stations were occupied in 1974 (in Eastern and southeastern States) to complete the U.S. data collection for the 1975 U.S. and World Magnetic Charts. The observation program was planned by J. D. Wood, and field work was accomplished by G. W. Brougham. The repeat survey data are deposited in the World Data Centers for worldwide distribution. As part of the master field of U.S. magnetic data, these data are a major source of input to the nautical and aeronautical chart navigation data. The nautical and aeronautical chart circulation approaches 50 million copies per year.

U.S. and world magnetic charts

Under the direction of E. B. Fabiano, magnetic data from more than 600,000 surface, marine, and aeromagnetic measurements from 1939 to 1974 were used to prepare magnetic charts of the United States and the world for epoch 1975. The U.S. chart series consists of separate charts for inclination, horizontal intensity, vertical intensity, and total intensity prepared every 10 yr, plus a chart of declination (compass variation) prepared at 5-yr intervals (Fabiano, 1975). Preliminary results show that the high rate of secular change in the United States has been sustained or increased, particularly in the southeastern United States. The maximum rate of change is 120 nT (gammas) per year off the southern coast of Florida.

A mathematical model using 168 spherical harmonic coefficients for the main field and 80 coefficients for the secular change field is being used to prepare the world magnetic charts. The complete series of world charts for five magnetic components will be published by the Defense Mapping Agency. Preliminary evaluation of this model shows an overall root-mean-square residual fit of less than 200 nT for the main field and 6 nT for the secular change field.

Geomagnetic instrumentation

R. W. Kuberry and A. W. Green, Jr., completed the design of a new geomagnetic data acquisition system for the U.S. magnetic observatory network. The system employs a three-component fluxgate magnetometer as well as a proton magnetometer. The components of declination, horizontal intensity, and vertical intensity, plus total field, are available in both analog and digital forms in real time. Permanent records are made on ½-inch digital magnetic tape and on analog paper charts (in world standard observatory formats). The new systems, which are being installed at selected geomagnetic observatories, will provide a computer-compatible product to investigators in the USGS and in the world scientific community.

Geomagnetic secular change

L. R. Alldredge completed a study of the causes of the rather sudden changes in the rate of change of geomagnetic components at observatories. Some scientists assumed that the "impulses" came from the core of the Earth. This idea demanded conductivities in the mantle that were orders of magnitude less than those derived from other concepts. Alldredge (1975) showed that the "impulses" could be explained by the sunspot cycle and the related westward-flowing ring-current variations. Alldredge was further able to quantify the first-order effects of the 11-yr solar cycle on the observatory component values and to derive a prediction for them that may hold 5 to 10 yr ahead and be useful in prediction.

D. G. Knapp, through modeling studies of the main geomagnetic field, has shown that the quadrupole field of the Earth has undergone a fairly constant rotation of 15 min of arc per year for the past several decades. The center of this clockwise rotation is in the north Pacific Ocean near the Gulf of Alaska.

Long-period geomagnetic field variations

W. H. Campbell analyzed geomagnetic records from 64 world observatories by computing variation amplitude spectra for the period range from 5 min to 4 h. A search was made for systematic behavior in the spectral composition that could be associated with time of day, season, solar cycle, activity level, component direction, or geographical location of the station. No consistent frequency location for peaks in spectral composition was found. Rather, the displays of spectral amplitudes A were mostly "linear" in form, often obeying $A \sim T^m$, where T is the period. The spectral slope m was usually close to 1.0 but varied at times from 0.5 to 2.0. The amplitudes always showed a maximum at the auroral zone latitudes, a minimum near 20° to 40°, and a minor maximum near the equator. The positions shifted equatorward with increasing activity. The relative growth in amplitude with rising activity varied with latitude. Seasonal peaks in activity were found in equinoctial months. A summertime minimum occurred at auroral zone stations; elsewhere, an enhancement occurred during the summer. General findings, emphasizing the North American Hemisphere and 1965, are presented in a number of tables and graphs (Campbell, 1976). Since induced currents from geomagnetic variations can interfere with corrosion monitoring systems on long fuel pipelines and can contribute to corrosion, particularly at auroral latitude and equatorial electroject locations, this study is being used to evaluate potential induced-current problems on the Alaska oil pipeline.

Source fields of geomagnetic pulsations

A. W. Green, Jr., conducted theoretical and experimental studies on the source fields of geomagnetic pulsations in the frequency range from 10^{-3} to 10^{-1} Hz. This study is aimed at achieving a better understanding of natural electromagnetic sources used in magnetotelluric investigations of the Earth's crust. A specific objective is to determine the relative roles played by "wavelike" and "currentlike" sources in the production of anomalous vertical electric- and magnetic-field components that give rise to erroneous geologic interpretation and data scatter. As part of the experimental program, Green has built a system for sensing and recording all six components of the electromagnetic field in the range from 10^{-3} to 2.0 Hz and placed it in operation at the Boulder magnetic observatory.

As another part of this research, A. W. Green, Jr., and C. O. Stearns (USGS) and V. A. Troitskaya (Institute of Physics of the Earth, Moscow, U.S.S.R.) have been studying the relationship between the worldwide characteristics of geomagnetic pulsations and some parameters of the Earth's magnetotail.

Simultaneous high-resolution recordings of geomagnetic pulsations of the class Pi 2 have been analyzed at a network of 10 Soviet and U.S. observatories. Analysis of spatial amplitude patterns suggests that the Pi 2 source is along the geomagnetic field lines in the midnight meridian, which pass through the inner edge of the magnetotail plasma sheet. The Pi 2's were treated as aperiodic events, and a spectral analysis was made by the Fourier in-

tegral transform method. The dominant spectral peaks were shown to be harmonically related and globally coherent. A significant result of this investigation is the discovery of large-amplitude power spectra peaks at periods much longer than the "visual period" and of the order of 300 s. The frequencies of these peaks are in excellent agreement with a theoretical magnetohydrodynamic model of Pi 2 generation at the plasma sheet edge, followed by guided-mode propagation along a narrow field-line path. Inasmuch as the theoretical model is frequency sensitive to the position of the edge of the magnetotail plasma sheet, observed shifts of the longest period spectral peak in the computed data are believed to be diagonostic of the position of the plasma sheet edge and the auroral oval.

APPLIED GEOPHYSICS TECHNIQUES

Resistivity of oil shales

Vertical electrical soundings by D. L. Campbell in the Piceance basin, Colo., showed coefficients of electrical macroanisotropies in the lower oil shales ranging from about 2 in the basin center to about 9 on the flank of the basin. These are among the largest macroanisotropies ever reported and are probably due to a complex of isolated horizontal aquifers within the lower part of the shale section. Laboratory measurements on a rich oil-shale sample from the Piceance basin indicate a value of 2.1 for the coefficient of electrical microanisotropy. The field study indicates that the "leached zone," an aquifer in the upper Green River Formation oil shales that is well defined near the basin center, splays into many thin water-bearing horizons extending throughout the oil-shale section toward the basin flanks. These thin horizons are probably recharged through a complex of near-vertical fissures that appears to become denser and to penetrate more deeply toward the basin flanks.

Electrical soundings in the Triassic basin

A resistivity study of the Deep River Triassic basin near Durham, N.C., by H. D. Ackermann showed a marked resistivity contrast between the Triassic rocks and the underlying metasedimentary and plutonic rocks. The thickness of the Triassic rocks was determined by 32 Schlumberger soundings, and the interpretation of one of the soundings agreed with the depth to pre-Triassic basement projected from a nearby deep well. Resistivity surveys appear to be the most effective geophysical method yet tested for investigating the depths and internal structures of the Triassic basins.

Digital magnetotelluric system developed

W. D. Stanley, in cooperation with the National Bureau of Standards, built and tested a magnetotelluric system using a three-component cryogenic magnetometer. The magnetometer has a sensitivity of better than 10^{-5}, a frequency response of 1 kHz, and a dynamic range of 500 nT. A lightweight cartridge-type digital recorder provides 12-bit digitization of the 3 magnetic-field and 2 electric-field channels. The recorder has a communications output interface so that data can be sent over standard telephone lines from the field to USGS computers. A microcomputer system currently under development will be used as a system controller and for processing magnetotelluric data in the field to make for more efficient field operations. The magnetotelluric sounding system has been tested in Yellowstone National Park and will be used in its initial field applications for detecting deep conductive hydrothermal systems and for investigating possible heat sources, such as magma chambers. It is capable of magnetotelluric soundings to depths of 100 km and will thus provide information on the electrical properties of the upper mantle. The basic instrument system can also be used for making controlled-source electromagnetic soundings and direct-current and magnetostatic mapping to depths of 3 to 5 km.

Logging of waste-disposal wells

W. S. Keys and A. E. Hess made geophysical well logs of waste-injection and waste-monitoring wells at Stuart, Fla., to determine the zones of highest permeability and porosity suitable for waste injection and to locate zones of low permeability that would prevent contamination of overlying aquifers. Temperature, natural gamma, caliper, density, acoustic velocity, neutron, resistivity, and acoustic televiewer logs were run. The acoustic velocity logs indicate porosities in the range of 10 to 35 percent for limestone and 15 to 40 percent for dolomite. Numerous fractures located and oriented from the televiewer pictures have a mean angle of dip 54° to the southeast. The logs suggest that the porosities are generally high in the two wells having two well-defined zones of high permeability, one at about 610 m and one near the bottom of each hole below 884 m. Resistivity measurements indicate that, in permeable zones below 884 m, water resistivity may be less than 0.18 ohm-m, or the equivalent of approximately 35,000 m/l of dissolved solids.

Cauldron near Silver Cliff, Colorado

A gravity survey by M. D. Kleinkopf and D. L. Peterson defined a 12-mGal gravity low that was interpreted as indicating a previously unrecognized volcanic subsidence cauldron about 4 km northeast of Silver Cliff, Colo. Subsequent surface geologic studies verified the feature, which is expressed as a topographic depression covered mainly with rhyolite tuff and breccia and surrounded by Precambrian gneiss. Three-dimensional modeling of the gravity data indicates that about 1,000 m of low-density material fills the subsidence feature.

A new satellite model of the geomagnetic field

J. C. Cain, W. M. Davis, and R. D. Regan recently constructed the most detailed satellite model yet produced using data from the Polar Orbiting Geophysical Observatories. Three spacecraft, POGO–1, 2, and 3, carried rubidium-vapor magnetometers that measured the Earth's magnetic field from late 1965 through 1970 at altitudes ranging from 397 to 1,500 km at all latitudes. This model was derived by separating from the measured field readings the effects of the electrical currents in the ionosphere and the magnetosphere. The resulting model, the most precise so far calculated, represented the data to an accuracy of only 3 nT (the Earth's field ranges from 24,000 to 72,000 nT). The results of this work show that the signals from the magnetized crust have half wavelengths as large as 1,400 km. It was previously thought that the geological structures were much too small to have such a large scale. This result is being evaluated for its relation to new developments in global tectonics.

Smaller magnetic features have also been observed in central and western Africa, at several locations in the oceans, and near Kursk in the U.S.S.R. This last anomaly is the most intense and appears to be associated with the 200,000-nT anomaly observed near the surface. The Russians had previously claimed that this feature was very narrow and was not detectable at aircraft altitudes of 3 km. Although none of these newly discovered magnetic anomalies have yet been interpreted, they must arise from intensely magnetized material covering areas of several hundred kilometres.

Exploration for uranium

T. W. Offield directed a study of a uranium area in the Texas coastal plain involving (1) aerial and ground magnetometry and very low frequency (VLF) electromagnetic surveys; (2) aerial four-channel gamma-ray spectrometry, multiband photography, and thermal infrared imagery; (3) induced polarization profiling; (4) resistivity profiling and soundings; and (5) gravity profiling. Preliminary analysis of the field data indicates that ground magnetic profiles show significant differences between the oxidized and reduced geochemical cells on opposite sides of shallow uranium roll fronts. Conglomeratic channel fillings (potential uranium host rocks) in the Catahoula Formation have higher thermal inertia than surrounding rocks and commonly show in predawn thermal images as distinctly warm areas. Study by B. D. Smith, J. W. Cady, J. J. Daniels, and D. L. Campbell of the induced polarization pseudosections suggests very subtle effects associated with either uranium roll fronts or the geochemical changes across them. As the metallic mineral content of the rocks is extremely small, the observed polarization effect may relate in part to variations in clay mineralogy associated with the occurrence of ore. In ground VLF profiles taken by J. N. Towle and V. J. Flanigan, conductivity variations were not indicative of ore bodies but served to distinguish between dry, wet, and silicified fault zones.

Exploration for coal

W. P. Hasbrouck and M. L. Botsford conducted experiments in the Powder River Basin of Wyoming to evaluate the effectiveness of gravity exploration in locating the edges of thick and strippable coals and to develop a magnetic method to assist geologists in mapping the boundary between burned and unburned coals. Preliminary indications are that high-precision gravity surveys can be used to trace the sharp edge of a thick seam and that magnetic surveys indicate the extent of a burned-coal facies. If these early findings are substantiated, better estimates of strippable coal reserves can be made with much less costly exploratory drilling.

West Texas ground-water study

Three test holes drilled in Culberson, Jeff Davis, and Presidio Counties, Tex., substantiated the interpretation of vertical electrical soundings made by W. D. Stanley. A hole near Valentine confirmed that a 10-ohm-m zone interpreted from resistivity data was a tuff unit with good-quality water. Another hole near Van Horn also confirmed the resistivity interpretation of a good producing aquifer down to 340 m. A third hole, southwest of Van Horn, penetrated a massive clay aquiclude predicted by the resistivity interpretations.

Electromagnetic fields about grounded wire

Formal mathematics and computer programs were developed for computing all three components of both electric and magnetic fields on or above the surface of a layered Earth for a grounded dipole or finite wire source. The computer programs, according to W. L. Anderson, are designed to use either improved numerical integration techniques or convolution for evaluation of the integrals. In addition to the fields themselves, coupling ratios are computed for a number of special cases. The results can be expressed in either the frequency domain or the time domain.

Geomagnetic field models in magnetic surveys

As part of the satellite magnetometer experiment, R. D. Regan and J. C. Cain have studied the utility of geomagnetic field models in the reduction of magnetic survey data. The results are directly applicable to standard magnetic surveys where global geomagnetic field models, usually computed from spherical harmonic series, are becoming of increased importance. Basically, when used correctly, a numerical model of sufficient complexity, including adequate secular variation correction, provides a suitable representation of the regional field. The best known and mostly widely used of the available field models is the International Geomagnetic Reference Field (IGRF). However, the IGRF may not be suitable for the reduction of all magnetic survey data because of its imperfect fit to the main field, particularly for the years since 1963.

A possible transform fault at Kilauea Volcano

Self-potential (SP) studies in the lower eastern rift zone of Kilauea Volcano in Hawaii by C. J. Zablocki revealed a small-amplitude linear anomaly about 1 km in length and trending transverse to the direction of the rift. This feature, near Puu Honuaula, coincides with a general epicentral area of recurrent shallow earthquake swarms and with an apparent offset in the rift zone. A possible interpretation is that the SP anomaly is caused by a permeable vertical fracture containing hot water from a heat source at depth. Ground deformation west of the anomaly and frequent earthquakes south of the rift zone support the earlier concept that the southern flank is moving seaward owing to forceful diking in the rift zone. East of the anomaly, however, the distinct aseismicity of the rift zone suggests that horizontal dilation caused by intrusions is symmetrical and that no appreciable strains accumulate. The net differential horizontal ground movements on opposite sides of this suspected fault may resemble those that develop across transform faults along mid-oceanic ridges.

GEOCHEMISTRY, MINERALOGY, AND PETROLOGY

EXPERIMENTAL AND THEORETICAL GEOCHEMISTRY

Neutralization of acid mine water

F. E. Senftle and F. D. Sisler demonstrated by laboratory experiments that anerobic activity will neutralize acid mine water. The process is accelerated by inserting electrodes in the bottom and surface of the water. Sewage sludge can be used as the nutrient source, and the process generates some electrical power and forms elemental sulfur.

Lead isotopes, ore genesis, and ore-prospect evaluation

Lead-isotope analyses of two Kuroko-type ores (submarine volcanic exhalative) and one epigenetic ore from Japan, three epigenetic series from Indonesia, and two ores from Peru by M. H. Delevaux showed lead compositions that overlap those of open-ocean pelagic and continental sediments. The isotopic composition of these leads does not correspond with that of ocean-ridge or intraplate volcanic rocks that represent oceanic mantle. The Tonga-Kermadec arc also has been shown to have oceanic mantle values (Oversby and Ewart, 1972). Tatsumoto (1969) has shown that volcanic rocks on the eastern side of Japan also contain leads characteristic of pelagic sediments. B. R. Doe and R. E. Zartman, in attempting to place the lead data into the context of plate tectonics, demonstrated that submarine exhalative ores of Devonian and Triassic age, collected by W. E. Hall from the Shasta district, have lead-isotope ratios characteristic of oceanic mantle. Rocks and ores of Jurassic age and younger in the Shasta district have lead values similar to those of pelagic sediments. P. W. Lipman (unpub. data, 1975) suggested that the Devonian and Triassic arc environment in the Shasta district was a primitive arc similar to Tonga and Kermadec. The subduction of lithified pre-Jurassic sediments as proposed by Hamilton (1969) explains these data. This model suggests that lithification controls the subduction of sediments. Lithified sediments are apparently available in mature island arcs and continental margins but are not available in primitive island arcs.

Thermochemistry of fossil-fuel formation

The thermochemistry of 140 common organic compounds with respect to deoxygenation reactions was examined by Motoaki Sato. In general, oxygen-rich compounds of organic remains could transform to carbon-hydrogen-rich compounds of fossil fuels through spontaneous decarboxylation and dehydration reactions, even at room temperature. Given geologic time, fossil fuels could form from buried organic remains in an ordinary diagenetic environment. High temperatures would accelerate the rate of transformation but are not an essential requirement for the formation of fossil fuels. The transformation reactions are exothermic, so that the process itself could create abnormal temperature gradients and thus accelerate itself.

Calorimetric studies

R. A. Robie and B. S. Hemingway determined the heat capacities of muscovite, pyrophyllite, magnesite, $KAlSi_3O_8$ glass, and $NaAlSi_3O_8$ glass, measured between 12 and 385 K, and their standard entropies determined by means of adiabatic cryogenic calorimetry. The heat capacities of low albite, analbite, sanidine, microcline, magnetite, hematite, muscovite, pyrophyllite, and periclase were determined by differential scanning calorimetry between 300 and 800 K. New values for the enthalpy of formation of kaolinite, muscovite, low albite, anorthite, and gibbsite were obtained from heat-of-solution measurements using HF (aqueous) or the solvent.

Alteration processes in mafic and ultramafic rocks

An experimental evaluation of mineral stability relations in the system MgO-SiO_2-H_2O at elevated pressures and temperatures has been made by J. J. Hemley and J. W. Montoya (Anaconda Company) and P. B. Hostetler and C. L. Christ (USGS). The activity of silica is the dominant control on geochemical processes in this system and therefore on processes involving mafic and ultramafic rocks. The results of this study apply particularly to serpentinization, talc-carbonate alteration such as that associated with mercury deposits, development of brucite, retrograde reactions of metalliferous skarns, and the controls of talc-bearing assemblages in high-grade metamorphic terrane.

In this type of study, reactions involve both the fugacity of water and the activity of silica, so that plots of the intersections of one type of data can define invariant points of the other. Combined studies provide more information than simple dehydration studies. Aqueous equilibria studies reach equilibrium faster than solid-liquid reactions. This study defines a value of ΔG_{f298} for talc of -5526.8 kJ/mol.

Laser Raman spectroscopy of fluid inclusions

Edwin Roedder (USGS), in a cooperative effort with G. J. Rosasco (National Bureau of Standards) and J. H. Simmons (Catholic Univ.) looked into the feasibility of laser-excited Raman spectroscopy for nondestructive analysis of specific phases in single fluid inclusions. The technique uses a low-power He-He laser for optical alinement; then a powerful argon laser is focused on the inclusion with microscope optics perpendicular to the first set. Scattering and fluorescence in this intense illumination (50 MW/cm^2) make the beam visible even in gases, so that it can be directed into the desired phase. Raman emission (from the given phase only) is detected with special electronics and processed via several procedures. A series of special samples was prepared and run, and, even at this early stage, some fascinating potentials have been proven. It will not be a panacea, but its greatest promise is in some otherwise intractable analytical problems such as SO_4 in daughter crystals (and its distinction from sulfide in solution), CO_2^0 vs HCO_3^{-1} vs CO_3^{-2} in solution, organics in water solution, nitrogen and CO in liquid CO_2, and perhaps C^{12}/C^{13} ratios on 10^{-8}-g samples. Several of these have already been verified by good peaks on a nice, clean, low-background spectrum from natural inclusions.

Na-K distribution between hornblende and melt: a possible geothermometer

R. L. Helz calculated the distribution coefficient for the reaction:

$$Na^+ (A \text{ site of hornblende}) + K^+ (\text{melt}) +$$
$$K^+ (A \text{ site of hornblende}) + Na^+ (\text{melt}) +$$

for the 24 hornblende-melt pairs obtained by partial melting of three basalts at $PH_2O = 5$ kb. The distribution coefficient:

$$kb = \frac{(K/Na) \text{ hornblende}}{(K/Na) \text{ melt}}$$

shows a well-defined linear variation with temperature and may be a usable broadgage geothermometer, if the composition of the melt in equilibrium with a given hornblende can be determined.

Bulk analysis of thin sections by electron microprobe

Bulk chemical analyses of thin sections by electron microprobe (U.S. Geological Survey, 1972, p. 197) by J. R. Lindsay on sections furnished by G. W. Leo

generally supported field relations and petrographic observations. The thin sections represent a suite of 18 samples including altered diabase, amphibolite, and calc-silicate hornfels produced by progressive contact metamorphism and associated with metasomatic magnetite deposits in the Samli area of western Turkey (Leo, 1972). Although some of the analytical values exhibit excessive scatter for petrographically similar rocks, the analyses in general are acceptable, given the small sample size (2 to 10 mg) and consequent analytical uncertainties. Normative plots indicate that (1) diabase and amphibolite are compositionally related and are similar to average compositions of basalts and well-studied orthoamphibolites and (2) calc-silicate hornfels appears to have been derived in part from amphibolite and in part from dolomitic limestone, which underlies much of the region.

MINERAL STUDIES AND CRYSTAL CHEMISTRY

CRYSTAL CHEMISTRY OF THE SILICATES

Cation distribution in pyroxenes

Two pyroxenes, one a low-calcium pigeonite ($Wo_{4.2}En_{40.6}Fs_{55.2}$) from a relatively quickly quenched andesitic pitchstone (Virgo and Ross, 1973) and the other a hypersthene ($Wo_{2.0}En_{57.6}Fs_{40.4}$) from lunar anorthosite 15415 (Stewart and others, 1972), were studied by H. T. Evans, Jr., who used X-ray methods to determine the degree of ordering of the cations on the *M*1 and *M*2 crystallographic positions in the crystal structure. For the Mull pigeonite, least-squares analysis of 861 X-ray intensities measured with the Picker automatic diffractometer revealed that *M*1 position contains [$Mg_{0.68}$(Fe, Mn)$_{0.31}$$Ti_{0.01}$] and the *M*2 position contains [$Mg_{0.13}$(Fe, Mn)$_{0.79}$$Ca_{0.08}$]. This represents a degree of ordering with respect to iron in *M*2 of about 44 percent. Least-squares refinement of 327 X-ray intensities from the lunar hypersthene shows that the *M*1 and *M*2 sites contain ($Mg_{0.83}Fe_{0.17}$) and ($Mg_{0.31}Fe_{0.63}Mn_{0.02}Ca_{0.04}$), respectively. This represents a degree of ordering with respect to iron in *M*2 of about 58 percent.

Growth rates of pyroxene exsolution lamellae

J. S. Huebner calculated the time required to grow augite lamellae in pigeonite by a diffusion-driven exsolution process. Augite lamellae up to 30 μm thick have been found in low-calcium pyroxenes in the ancient lunar noritic breccia 77215 as well as in pyroxenes from many other lunar and terrestrial rocks. The growth of lamellae can be described in terms of Ca-(Mg, Fe) volume diffusion at 800° to 1,150°C. The minimum suggested diffusion rate, obtained by extrapolation to 800°C of data for calcium, magnesium, and iron diffusion in oxides and silicates, is 10^{-19} cm^2 s^{-1}. The maximum time needed to enlarge the augite lamellae from a discrete plane several hundred angstroms thick to 30 μm thick is 50,000 yr. The presence of such lamellae is not evidence for a longer period of annealing. Thus, we do not have to assume that the breccia was buried at great depth so as to maintain high-temperature diffusion processes for millions of years.

MINERALOGIC STUDIES

An index method for mineral identification

R. E. Wilcox demonstrated how indices of refraction of immersed mineral fragments can be determined more rapidly and reliably by using dispersion coloration effects instead of the conventional Becke-line effect. The several means for producing this coloration have been tested extensively; one of the most practical and easiest to set up in the polarizing microscope is "central focal masking," in which a narrow beam of white light is produced by a constricted aperture at the focal point of the substage lens assembly and blocked by a central opaque dot at the focal point of the objective. The result is that the irregularities of the immersed fragment are sharply imaged on a dark field; they are red or orange if the immersion liquid is of slightly lower index, green or blue if the liquid is slightly higher in index, and a deep violet color if the fragment and liquid have matching indices. This technique is also useful in the quality control of mineral separations, where undesired constituents can be made to stand out in a strongly divergent color by mounting the sample in an immersion liquid that has a refractive index closely matching that of the desired constituent.

VOLCANIC ROCKS AND PROCESSES

HAWAIIAN VOLCANO STUDIES

Summary of 1974 Kilauea activity

Kilauea Volcano exhibited a variety of activity in 1974. The staff of the Hawaiian Volcano Observatory, with D. W. Peterson as Scientist-in-Charge, observed and recorded the activity, measured the deformation of the ground, monitored the seismicity, and conducted related studies. Other professional members of the observatory staff during the year

included R. I. Tilling, C. J. Zablocki, J. D. Unger, J. P. Lockwood, R. Y. Koyanagi, and E. T. Endo.

From January to June, the vents at Mauna Ulu overflowed repeatedly, and the lava shield reached a height of more than 120 m above the pre-1969 ground surface. Much of the lava was erupted during well-defined episodes characterized by fountains as high as 70 m and lava flows that traveled as far as 9 km from the vent. Each episode was accompanied by sharp deflation at Kilauea's summits monitored by tiltmeters. Between episodes, lava was generally confined to the immediate vicinity of the vents, though some quiet overflows occurred. During these intervening periods, Kilauea's summit reinflated, and the number of shallow earthquakes in the caldera increased. Beginning in early June, activity at Mauna Ulu progressively declined, the surface of the lava column steadily dropped, and repeated rockfalls from the vent walls produced a crater that ultimately measured about 100 m in diameter. In late July, the lava disappeared below the rubble-choked floor of the crater, and nearby seismographs stopped recording harmonic tremor. Copious fumes were emitted until the end of the year, but eruptive activity was not renewed.

Brief but spectacular eruptions took place elsewhere on Kilauea on July 19–22, September 19, and December 31, 1974. The July eruption was located along fissures in the southern and southeastern parts of the summit region. Lava covered the floors of Keanakakoi Crater, Lua Manu Crater, the southeastern part of the caldera, and adjacent areas. About 10×10^6 m^3 of lava was erupted. The September eruption was mostly within Halemaumau and also along a fissure that extended southwestward across the caldera floor to the wall. The new lava in Halemaumau reached a depth of about 19 m before draining back to leave a new pond about 10 m deep that completely buried the previously exposed 1968 and 1971 lava. The new lava on the caldera floor partly buried the flows erupted in September 1971. The eruption lasted 8 h; a total of 10.9×10^6 m^3 of lava was erupted, but, after drainback, about 6.1×10^6 m^3 remained.

The December 31 eruption took place along an in-place system of fissures between the caldera, the Koae fault system, and the southwestern rift zone. Fountains had a maximum height of 100 m, and flows had a total length of 12 km. During the 6-h eruption, about 15×10^6 m^3 of lava was erupted. The eruption was accompanied and followed by a large deflation of the Kilauea summit region and an intense earthquake swarm along and near the southwestern rift zone. Between December 31 and January 5, nearly 200 earthquakes of magnitude 3 (Richter scale) or stronger were recorded, 5 of which exceeded magnitude 5.

Mauna Loa Volcano stirs

Mauna Loa Volcano, quiet since 1950, showed preliminary signs of reinflation during 1974. The average daily count of shallow (0 to 5 km deep) caldera earthquakes recorded at Mauna Loa's summit by the seismic network of the Hawaiian Volcano Observatory increased abruptly from less than 10 to several dozen in late April. The annual monitor of precision-measured geodimeter lines in August revealed significant extension along several lines. To provide improved surveillance, two new seismic stations were installed at the summit, and additional geodimeter lines were established. After a brief seismic swarm in August, when the earthquake count one day reached a maximum of 455, the daily count varied from 40 to 180 until December. From December 7 to 20, an intense seismic swarm was centered below the summit caldera; during this time, the daily earthquake count reached as high as 1,500, including several that exceeded magnitude 3 and one that measured 4.5. An emergency reoccupation of the geodimeter network, with the assistance of a U.S. Marine helicopter, revealed further significant extension of lines. After the swarm subsided, the daily count dropped back to between 30 and 120.

Preliminary locations have been determined for earthquakes larger than about $M=2.5$. They generally form an alinement from the summit caldera extending for a few kilometres down the southeastern margin of the southwestern rift zone. Focal depths are generally about 5 km. Scattered flurries of earthquakes also occur beneath the southeastern and western flanks of the volcano.

Dike intrusion causes rift-zone dilation

Examination by D. A. Swanson, W. A. Duffield, and R. S. Fiske of triangulation, trilateration, and leveling data obtained throughout the 20th century showed that the southern flank of Kilauea was displaced upward and away from the rift zones by as much as several metres. The amount of horizontal displacement approximates the probable amount of dilation that accompanies the intrusion of dikes in the rift zones and is greatest for periods of most intense activity, as is evidenced by the frequency of eruptions. The displacement and seismic events that take place on the southern flank soon after intrusive activity indicate that the displacement is the result

of forceful intrusion in the rift zones, not the cause of relatively passive intrusion. In contrast to the southern flank, seismic and geodetic data indicate that the northern flank is virtually immobile, probably because Kilauea was built on the southern slope of Mauna Loa and was consequently influenced by Mauna Loa's gravitational stress system, which favors displacement away from the volcanic edifice. The northern flank is unbuttressed and free to move away from the edifice when prompted by the forceful intrusion of dikes.

The active part of Kilauea's eastern rift zone has apparently migrated several kilometres southward with time, as is shown by the location of recent vents along the southern edge of the rift zone. The location of the axis of a positive gravity anomaly along the northern edge of the active rift zone also suggests southward migration.

The Hilina fault system is considered to be a gravity-dominated system not directly related to the rift zones. Gravitational instability resulting from uplift and seaward displacement is eventually relieved by normal faulting along the seaward part of the southern flank. The Hilina faults are thought to bottom at shallow depth without intersecting magma reservoirs, except possibly along part of the lower eastern rift zone, where the fault system impinges upon the rift zone. Strains have been accumulating within the Hilina system throughout this century, and a high level of instability may have been reached.

Finite-element analysis of cooling of Alae lava lake

The analysis of the cooling of Alae lava lake, Hawaii, that was started by D. L. Peck (USGS) in a cooperative program with J. C. Jaeger (Australian National Univ.) (U.S. Geological Survey, 1974, p. A127) was extended by means of a computer program developed by H. R. Shaw and M. S. Hamilton. The program, which is based on finite-element analysis, takes into account the cooling by rainfall as well as the latent heat of the basalt and can use either a constant or a variable thermal diffusivity for the lava. The abundant temperature data collected over a 4-yr period from the 15-m-thick ponded basalt flow can be approximately duplicated by computed temperatures based on a constant diffusivity for the basalt of 0.006 cm^2/s and a latent heat of 80 cal/g. A better match can be achieved by using a variable diffusivity. The computations indicate that the thermal conductivity decreases significantly with increasing vesicularity of the basalt, in agreement with conclusions by Robertson and Peck (1974) based on laboratory measurements; the computations also indicate that conductivity increases significantly with increasing temperature, in agreement with unpublished laboratory studies of samples from Alae crater by K. Kawada (Univ. of Tokyo). Cooling by the abundant rainfall, which averaged 2.50 m/yr, did not substantially decrease the 1.14-yr time for solidification of the lava lake. It did, however, drastically decrease the duration of postsolidification cooling; the total time for cooling to 100°C, for example, was decreased from 19.6 to 4.0 yr.

Mechanism of formation of pillow lava

Underwater observations and motion pictures taken by J. G. Moore of growing pillows off the southern coast of Hawaii demonstrated that pillows do not grow by stretching of an outer plastic skin, as is commonly thought. Rather, they expand, branch, and lengthen as fresh lava inside the pillow (fed from upslope) distends and cracks the outer crust. New crust is continuously formed adjacent to one or more incandescent opening cracks. The pillow lobe grows sporadically downslope as a given crack stops spreading and a new one forms more toward the distal end of the growing pillow tongue. Hence, most young pillowed lava flows are composed of a tangled mass of cylindrical interconnected flow lobes. Independent discrete sacks are rare.

Fast-spreading cracks (~5 cm/s) are commonly zigzag in form and produce corrugations perpendicular to the crack. Slow-spreading cracks (~0.1 cm/s) produce smaller fault slivers parallel to and tilted away from the crack. Ridges of both types record the history of growth of the pillow crust; they account for the parallel ribbed appearance of fresh pillows in ocean-bottom photographs.

The development of pillow crust adjacent to opening cracks is analogous to sea-floor spreading in which oceanic lithosphere is formed at and diverges from oceanic spreading ridges. The fault slivers in pillow crust can be compared with the outward tilted fault blocks that bound slow-spreading ocean-ridge systems.

Age of some Pacific seamounts

Many thousands of seamounts, most the remnants of extinct volcanoes, particularly those that form linear chains, can be explained by the eruption of material from "hotspots" in the mantle onto moving plates. Most, however, must either form at or near spreading ridges or be the result of random mid-plate eruptions. To test these two hypotheses,

G. B. Dalrymple and D. A. Clague dated four seamounts in the north-central Pacific by means of conventional K-Ar and $^{40}Ar/^{39}Ar$ techniques.

Khachaturian and Rachmaninoff seamounts in the Musicians seamounts are 65.2±2.6 and 86.6±5.2 m.y. old, respectively. A single boulder of rhyolite dredged from the northern slope of the seamount beneath Necker Island in the Hawaiian chain has an age of 77.6±1.7 m.y., which suggests that Necker, previously dated as about 10 m.y. old, is a composite seamount constructed of both Cretaceous and upper Tertiary volcanoes. The minimum age of Wentworth seamount, which sits atop the Hawaiian Ridge near Midway, is 71±5 m.y. Like Necker, Wentworth appears to be another Cretaceous volcano that was subsequently incorporated into the Hawaiian volcanic chain. The ages of these four Cretaceous seamounts, which are equal to or slightly less than the age of the adjacent sea floor inferred from extrapolation of magnetic anomalies, indicate that these seamounts formed at or near the crest of the East Pacific rise.

"Absolute" plate-motion models based on "hotspots" premature

It has been proposed that linear volcanic chains on the Pacific plate, of which the Hawaiian chain is the best known example, were formed by the steady passage of older Pacific lithosphere over fixed melting anomalies in the asthenosphere or the deep mantle, at least during the last 70 to 80 m.y. It has further been proposed that the active shield-building southeastern ends of these chains form part of a fixed reference frame on Earth from which "absolute" plate motions can be derived. E. D. Jackson, (1974) however, recently pointed out that age data on volcanoes of chains in the Pacific are not linear when plotted against distance along the chains. This scatter appears to be a result in some cases of the use of inappropriate age data, in others of dating lavas of volcanoes whose tholeiitic and alkalic suite rocks have extended life spans, and in still others of dating volcanic rocks that represent a period of rejuvenated volcanism on older shields. However, in many cases, the scatter is demonstrably the result of real variable rates of emplacement of volcanic edifices along chains. The time scale of apparent irregular progression, where documented or suspected, ranges from 1 or 2 to 30 or 40 m.y., and the detailed rate of volcanic progression in the Hawaiian chain ranges from as little as −7 to as much as +24 c/yr. On the other hand, students of magnetic anomaly time scales maintain that spreading rates along oceanic rift systems in the major oceans of the world, including the Pacific, have been relatively constant over the last 70 to 80 m.y. Jackson suggests at least three major possibilities that may explain this apparent lack of kinematic agreement: (1) The rate of volcanic propagation of linear volcanic chains is not directly proportional to the rate of Pacific plate motion; (2) the East Pacific rise, while maintaining a steady spreading rate, has jumped or migrated in an irregular manner with time; or (3) the magnetic anomaly time scale is not linear. Of these alternatives, the weight of evidence at present favors the first, although all three mechanisms may be involved.

COLUMBIA PLATEAU STUDIES

Linear vent systems and eruption rates of Yakima Basalt

D. A. Swanson, T. L. Wright, and R. L. Helz found that flows belonging to two sequences of flood basalt in the Miocene part of the Yakima Basalt, the vast Roza Member (volume, $>1.5\times10^3$ km^3) and the less extensive Ice Harbor flows (volume, <10 km^3), were erupted from linear vent systems tens of kilometres long and a few kilometres wide. The Roza vent system is near the eastern edge of the Columbia Plateau, and the Ice Harbor system is near the center of the plateau. The vent systems parallel the trend of the Chief Joseph dike swarm and are characterized by remnants of spatter and tuff cones, local accumulations of thin pahoehoe flow units, bedded pumice, and dikes. The Roza flows cover vast areas and advanced many tens of kilometres from their vents. The Ice Harbor flows are much less extensive and are localized near their vents. Linear vent systems for other units can be inferred from outcrop patterns, and such systems may be typical for the Yakima Basalt. Using the dimensions of the vent systems and the rheologic model of Shaw and Swanson (1970), Swanson, Wright, and Helz estimate that the Ice Harbor flows were erupted at rates comparable to those of Kilauea and Mauna Loa, whereas the Roza flows were erupted at rates three to four orders of magnitude higher. The heat energy released during the short-lived Roza eruptions equals or exceeds the yearly global energy loss by conducted heat flow. Long-term rates of production for Yakima magma were comparable to rates of production for Hawaiian and Icelandic basaltic magma and do not necessarily imply unusually large concentrations of heat energy in the mantle.

CALDERA STUDIES

Caldera collapse breccia, San Juan Mountains, Colorado

In four large Oligocene calderas in the western San Juan Mountains—Lake City, Silverton, San Juan, and Uncompahgre—P. W. Lipman found that spectacular breccias are intermixed with thick intracaldera ash-flow tuffs that accumulated during caldera collapse. These breccias are divided into two intergradational types: mesobreccia, in which numerous small clasts are visible within single outcrops, and megabreccia, in which many clasts are so large that the fragmental nature of the deposit is obscure in many individual outcrops.

In general, mesobreccia occurs as thin tabular deposits locally interlayered with upper parts of the intracaldera ash-flow accumulations; it is readily interpretable as resulting from rockfalls and rockslides from the caldera walls. In contrast, the megabreccia is the dominant lower part of the caldera-filling sequence and contains only minor intermixed ash-flow material. The megabreccia is difficult to distinguish from possible precollapse caldera floor in places, but local lenses of welded tuff near the deepest exposed stratigraphic levels within the calderas indicate that these rocks are mostly megabreccia resulting from slumping and caving of caldera walls —but on a much greater scale—during the initial stages of caldera collapse.

Megabreccias similar to those in the western San Juan calderas occur on other eroded collapse structures in the Western United States, and the presence of such deposits may be useful guides to the roots of caldera structures in deeply eroded, highly altered, or structurally complex old volcanic terranes.

Megabreccia in Mount Aetna complex, Colorado

Priestley Toulmin III reported that identification and mapping of megabreccia and fossil landslide deposits have permitted more precise delineation of the outline of the caldera associated with the volcanic center near Mount Aetna in the southern Sawatch Range, Colo. Despite the nearly chaotic nature of the breccia accumulation, a crude internal stratigraphic succession seems to exist: the lower part of the mass consists principally of monolithologic breccia derived from the underlying bedrock, whereas more polymict breccias and breccias with a significant volcanic component are more prominent upward and toward the interior of the caldera. Such a succession implies that talus and landslide deposits along the margins of the depression are progressively overridden by transported and volcanogenic materials as the depression deepens and eruptive activity intensifies.

Age of rhyolite volcanism, Coso Mountains, California

The age and volume of rhyolitic volcanism in the Coso Mountains geothermal area of southern California were determined by M. A. Lanphere, G. B. Dalrymple, and R. L. Smith. The silicic eruptive centers, which include at least 31 recognizable rhyolite domes and flows, are distributed within an area of about 120 km^2. The total volume of erupted rhyolitic lava is about 2.4 km^3. Two basalt flows provide limits on the age of the rhyolite domes and flows. A basalt thought to be older than any of the rhyolites on field evidence has an age of 3.24 ± 0.10 m.y. A basalt that has an age of 0.038 ± 0.032 m.y. is thought to be younger than any of the rhyolites. The K-Ar ages measured on 16 of the domes range from about 0.04 ± 0.02 to 0.96 ± 0.15 m.y. Most of the units, however, appear to be between 0.05 and 0.15 m.y. old. There is no geographic progression or pattern of ages within the rhyolite dome field.

Volcano-tectonic implications of Glass Mountain and Mono Craters, California

Close similarities between the petrochemistries and structural settings of the Glass Mountain rhyolite complex, on the northeastern rim of Long Valley caldera, and the much younger Mono Craters, northeast of the caldera, suggested to R. A. Bailey that the evolution of the former provides information on the possible future evolution of the latter.

Geologic mapping of Glass Mountain by Bailey has shown that the lavas are more crystal rich in the lower part of the complex and that there is an apparent upward progression from early-stage subliquidus rhyolites to late-stage superliquidus rhyolites. Potassium-argon dates of 1.92 m.y. (Bailey and others, 1976) and 0.9 m.y. (Gilbert and others, 1968) indicate that this progression developed over a period of at least 1 m.y. The fact that the eruptive centers of Glass Mountain are on an arc concentric with the walls of Long Valley caldera suggests that they are on an outer caldera ring fracture and represent early leakage from the Long Valley magma chamber prior to its evisceration by the eruptions that produced the Bishop Tuff 0.7 m.y. ago.

R. W. Kistler (1966) has noted that the Mono Craters also lie on an arcuate ring fracture having an apparent diameter of 14 km. Additional, more extensive arcuate fractures and faults mapped by Bailey indicate that the ring-fracture zone is nearly 18 km in diameter and shows a cumulative down-

ward displacement of at least 200 m centripetally. These structural relations together with (1) the remarkable chemical homogeneity of the Mono Craters (Carmichael, 1967), (2) their very close petrochemical similarity to the older but structurally analogous rhyolites of Glass Mountain (Jack and Carmichael, 1968; Noble and others, 1972), and (3) their very young age (31,000 to 1,300 yr (Dalrymple, 1967; Friedman, 1968)) imply that the Mono Craters overlie a large, possibly active magma chamber. A tentative estimate of the depth to the chamber based on Carmichael's (1967) data is 6 to 22 km.

If the evolution of the Mono Craters is similar to that of Glass Mountain, pumice and ash eruptions can be expected to continue for several hundred-year intervals. Conceivably, these eruptions could eventually culminate in caldera-forming ash-flow eruptions similar to those that produced the Bishop Tuff and Long Valley caldera, but such an event would occur far in the future and would undoubtedly be preceded by abundant forewarning seismic activity. If the Mono Craters are underlain by an active magma chamber, it may be a potential source of geothermal energy, provided the "dry-hot-rock" method of heat extraction can be successfully developed.

PETROLOGIC AND PETROCHEMICAL STUDIES

Laramide magmatism and uranium-thorium fractionation, central Front Range, Colorado

In a continuing study of the petrology and chemistry of the early Laramide intrusions and volcanic rocks of the central Front Range, Colo., George Phair discovered that alkalic, alkali-calcic, calc-alkalic, and calcic, as well as tholeiitic, magma types all occur within this relatively small region. Recognition of this marked diversity invalidates earlier studies in which all of the chemical variations were assigned to a single line of descent.

Phair found that, although the magma types are closely related in time, they are geographically separable. Nepheline-bearing alkalic rocks occur only in the extreme north and south of the region. Northeast of the medial northwest-trending junction Ranch Breccia Reef, the region is potassic; southwest of the reef, it is sodic. The potassic province is further separable into a predominantly alkalic to alkali-calcic subprovince to the southwest and a predominantly calc-alkalic to calcic subprovince to the northeast by the Livingston Breccia Reef, which is in part followed by the tholeiitic Iron Dike.

High concentrations of uranium and thorium correlate with high sodium contents in the rocks and reach maximum value in the southwestern sodic province. Even greater enrichment of these elements occurs in the later sodic porphyry and calcium-poor rocks of the region, which is well known for its hydrothermal deposits of pitchblende. The relations strongly suggest that these deposits are the result of magmatic fractionation of uranium and thorium.

Trace-element variations, Summer Coon Volcano, Colorado

R. A. Zielinski completed a trace-element study of the Oligocene Summer Coon stratovolcano, eastern San Juan Mountains, Colo. The rocks range in composition from basaltic andesite to rhyolite and have similar ages. Chondrite-normalized REE patterns are strongly fractionated in comparison with oceanic-arc andesite-dacite sequences. Enrichment factors relative to chondritic abundances are 80 to 120 for La but less than 10 for Yb and Lu. Small negative europium anomalies characterize the rhyolites. Alkali and alkaline earth elements vary greatly. As SiO_2 increases, Ba increases from 900 to 2000 ppm, Rb increases from 35 to 90 ppm, Sr decreases from 900 to 350 ppm, K/Rb decreases slightly, Ba/Sr increases, U increases from 0.5 to 2.5 ppm, and Th increases from 2 to 7 ppm. Nickel in the andesites ranges from 40 to 70 ppm.

The origin of the andesites is interpreted in terms of nonmodal partial melting of a trace-element-enriched garnet-bearing plagioclase-poor source, possibly subducted crust that has converted to eclogite. Rhyodacite and rhyolite are interpreted as low-pressure crystal factionation products of andesite, in which crystallizing phases are hornblende rich in REE and plagioclase.

Chromite-ulvöspinel solid solution in alkalic basalts

M. H. Beeson reported that a wide variety of oxide phases showing extensive solid solution among the various end-members occurs in the basaltic lavas of the East Molokai Volcano, Hawaii. Some chromite grains, which occur as microphenocrysts in the groundmass and also as inclusions in olivine, contain more than 50 percent Cr_2O_3. Many of those chromite grains not entirely enclosed in olivine phenocrysts are continuously zoned from chromite at the core to ulvöspinel at the margins. Continuous solid solution between chromite and ulvöspinel has been reported previously in the tholeiitic lavas of Kilauea Iki and Makaopuhi and from lunar basalts, but this report of chromite-ulvöspinel solid solution in an alkalic rock suite appears to be the first.

Ultramafic inclusions in basalts

Xenoliths in basalts from the Western United States consist of magnesian spinel lherzolites in which at least four types of gabbroic and pyroxene-rich bands have formed, according to H. G. Wilshire and S. W. Shervais (1975). Gabbroic bands range from amphibole-rich olivine gabbro to gabbronorite and anorthosite. Nonfeldspathic bands include garnet pyroxenites and spinel pyroxenites of several types, amphibole-rich pyroxenite, and pure kaersutite. Each variety of compositional band has both igneous and metamorphic subtypes, and members of each group reveal a complex history of crystallization, subsolidus unmixing, recrystallization, and renewed fusion. Composite xenoliths show that there is also a broad sequence of emplacement of the main groups starting with chromium-rich magnesian spinel and garnet clinopyroxenites and ending with gabbros. This history suggests generation of the melts in an active diapir of upper mantle peridotite.

PLUTONIC ROCKS AND MAGMATIC PROCESSES

Granitic rocks of the southern part of Yosemite National Park, California

The granitic rocks of the Yosemite Valley, which were described in the classic report of Calkins (1930), were restudied by D. L. Peck with emphasis on their regional extent and interrelations. The El Capitan Granite forms a large pluton that extends 25 km southeast of the valley and is intruded by several small masses of the related finer grained Taft Granite. The younger Bridalveil Granite and Leaning Tower Quartz Monzonite are in small bodies near the southern wall of the valley. The Sentinel Granodiorite as mapped by Calkins consists of at least four distinct granitic units from three plutons; from east to west near Glacier Point, these plutons consist of the following: (1) The marginal phase of the Tuolumne Intrusive Series, (2) the marginal and core phases of a zoned pluton that is exposed over a large area in the drainage basin of Yosemite Creek, north of the valley (Kistler, 1973), and (3) the marginal phase of a large zoned pluton exposed along Buena Vista Crest, south of the valley. The latter pluton and another large zoned pluton centered on Washburn Lake, east of the valley, are both zoned from tonalite and granodiorite at the margin to fine-grained granite and granite porphyry at the core and are intermediate in age between the older El Capitan Granite and the younger Tuolumne Intrusive Series.

Mineralogical layering suggests multiple injections of magma in Lake Owens Mafic Complex, Wyoming

R. S. Houston and J. L. Ridgley reported that the Lake Owens Mafic Complex of Houston and others (1968) of southeastern Wyoming can be subdivided into three and possibly four units that may represent separate injections of magma. The lowermost unit, possibly only the exposed top of a thicker layer, consists largely of magnetite gabbro containing relatively sodic plagioclase ($An_{56\pm}$). Two successively overlying units are each marked by olivine (Fo_{80}) and calcic plagioclase (An_{70}), as well as by upward iron enrichment in the olivine, orthopyroxene, and clinopyroxene and upward enrichment of sodium in the plagioclase (to An_{56}). The upper part of each of these two units is magnetite gabbro, similar to the lowermost unit. Poorly exposed rocks suggest yet another overlying intrusive unit that is similar but whose initial olivine is more iron rich and whose plagioclase is less calcic—a situation that perhaps suggests fractional crystallization of the source magma.

Garnet pyroxenites from Sabah, Malaysia

Garnet pyroxenites and corundum-garnet amphibolites from the Dent Peninsula of eastern Sabah (North Borneo) were investigated by B. A. Morgan. These rocks occur as blocks in a slump breccia deposit of late Miocene age. The earliest formed minerals include pyrope-almandine garnet, tschermakitic augite, pargasite, and rutile. Cumulate textures are present in two of the six specimens studied. The earlier fabric has been extensively brecciated and partly replaced by plagioclase, ilmenite, and a fibrous amphibole. The bulk composition and mineralogy of these rocks are similar to those of garnet pyroxenite lenses within ultramafic rocks. Estimated temperature and pressure for the origin of the Sabah garnet pyroxenites are 850±150°C and 19±4 kb, respectively.

Origin of garnets in plutonic rocks, central Sierra Nevada batholith, California

Garnets, conspicuous though rare constituents of some plutonic rocks of the Sierra Nevada batholith, were studied by F. C. W. Dodge and L. C. Calk. The garnets have two different modes of origin. The less common almandine garnet probably formed at low prevailing oxygen pressure, possibly at considerable depth, during magmatic crystallization, whereas the more common almandine-spessartite or spessartite garnets have resulted from the concentration of manganese relative to iron in highly differentiated

melts. Contamination of granitic magmas by argillaceous impurities or metamorphism of the plutonic rocks do not seem to be likely modes of origin for the Sierra Nevada garnets.

Geochemistry and differentiation of a gabbro-diorite-tonalite-trondhjemite suite, Finland

Investigation of the Precambrian hornblende gabbro-biotite diorite-biotite tonalite-trondhjemite suite of the Uusikaupunki-Kalanti area, southwestern Finland, by J. G. Arth, Fred Barker, Z. E. Peterman, Irving Friedman, and G. A. Desborough showed that this suite with a continuous variation in SiO_2 from about 42 to 74 percent is the most complete trondhjemite suite known. Major and minor elements, including rare earths and rubidium, strontium, and barium, show consistent variations that fit a model of origin in which a slightly alkaline and moderately wet olivine-tholeiite liquid ($K_2O=$ 0.7 to 0.9 percent and $H_2O=3$ to 4 percent) differentiated by first settling out hornblende, then hornblende and plagioclase, and lastly hornblende, plagioclase, and biotite.

Emplacement and crystallization of the Humbug stock, Colorado

M. A. Kuntz reported that the Humbug stock, a relatively homogeneous quartz monzonite body in the Ten Mile Range, Colo., was emplaced as a semisolid mass of partially crystallized magma; emplacement was achieved in part by faulting along the margins of the body. A hornblende-rich facies occupies the central and northern parts of the stock, and a biotite-rich facies characterizes the western, southern, and eastern margins. Differences of quartz, plagioclase, and alkali feldspar between the two facies are not statistically significant.

Age data so far obtained present a complex and somewhat confusing picture but may provide useful information on the cooling history of the body. Potassium-argon ages of biotite (determined by C. E. Hedge) and fission-track ages of zircon and apatite (determined by C. W. Naeser) suggest that the stock crystallized at 41 ± 2 m.y. (on the basis of biotite ages), cooled relatively slowly to a temperature of about 300°C at 34 ± 4 m.y. (on the basis of zircon ages), and reached a temperature of 100°C about 15 ± 5 m.y. ago (on the basis of apatite ages). Alternatively, the apatite ages may reflect a reheating event about 15 m.y. ago.

Origin of compositionally zoned plutons of the Sierra Nevada batholith, California

Investigations by P. C. Bateman showed that the marginal rocks of compositionally zoned plutons of the Sierra Nevada typically contain abundant hornblende and biotite but little quartz and little or no K-feldspar, whereas interior rocks contain abundant quartz and K-feldspar but little or no hornblende. Analysis of modal patterns in the light of experimental data shows that such plutons solidified inward by the marginal accretion of crystals. Because crystallization proceeded with falling temperature, successively less refractory minerals were available for marginal accretion. Typical Sierran magmas were saturated in plagioclase, hornblende, and biotite when they reached the present level of exposure and consisted of both crystals and melt. Most magmas were also saturated in quartz but had been undersaturated earlier. The magmas became saturated in K-feldspar only after the temperature of the magma had fallen appreciably below that at the time of emplacement. K-feldspar megacrysts grew where K-feldspar was being precipitated faster than crystals were being deposited on the plutons wall or settled downward. In magmas containing little potassium, K-feldspar began to crystallize much later than quartz, whereas in magmas moderately rich in potassium, K-feldspar began to crystallize shortly after quartz. In the eastern part of the batholith (White Mountains), where potassium-rich magmas crystallized to rocks with more K-feldspar than quartz, K-feldspar probably began to crystallize before quartz.

Movements of core magmas during solidification produced discontinuities and concentrically arranged "nested" plutons. Penetrations of the core magma through the crystallized carapace produced plutonic sequences in which the concentric arrangement has been lost.

METAMORPHIC ROCKS AND PROCESSES

Age of amphibolites associated with alpine peridotites in the Dinaride ophiolite zone, Yugoslavia

M. A. Lanphere and R. G. Coleman (USGS), Steven Karamata (Univ. of Belgrade), and Jakob Pamic (Institute for Geological Research, Sarajevo, Yugoslavia) completed a geochronologic study of amphibolites associated with two alpine peridotite masses in the Dinaride ophiolite zone of Yugoslavia. Pargasite from corundum-pargasite amphibolite interlayered with peridotite in the Krivaja-Konjub and Zlatibor massifs and amphibole from garnet amphibolite at Zlatibor yielded K-Ar ages of 160 to 170 m.y. The amphibolites and peridotites occur within a complex sedimentary-volcanic assemblage that is similar in lithology and tectonic style to the Franciscan of the Western United States. The am-

phibolites are considered products of a Jurassic metamorphic event that may represent deep-seated metamorphism initiated by tectonic emplacement of the Yugoslavia ophiolites into the sedimentary-volcanic assemblage. By analogy with California, the associated alpine peridotites, gabbro, diabase, and basalt can be interpreted as Jurassic oceanic crust and upper mantle that probably formed with the ancient Tethyan Sea.

Reassessment of the concept of "burial metamorphism"

E-an Zen made a review of several low-grade metamorphosed terranes that have been referred to as altered by "burial metamorphism." (For example, see D. S. Coombs, 1961). Burial metamorphic rocks are mainly of low grade and have been metamorphosed without being affected by penetrative deformation, i.e., without development of schistosity. Many burial metamorphic rocks characteristically show zeolitic assemblages. Rocks with similar mineral assemblages occur in orogenic belts (for example, in Silurian-Devonian rocks of New Brunswick, Canada, and in the Helvetian realm of the western Alps). Experimental data of the phase equilibria of the typical zeolite minerals laumontite and analcime give the maximum stability fields for the metamorphism of these rocks. In nature, other factors such as additional chemical components and the condition of P_{H_2O} less than P_{total} tend to restrict the stabilities of these zeolites to lower pressures, perhaps to no more than 1 to 2 kb. Under such conditions, massive volcanic rocks and graywackes tend to fail by brittle fracture rather than by developing penetrative schistosity. Thus, many instances of burial metamorphism may merely signify metamorphism at very shallow depth and low temperatures.

GEOCHEMISTRY OF WATER AND SEDIMENTS

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.

Water near an active volcano

Water samples were periodically collected by C. J. Zablocki and R. I. Tilling in 1973 and 1974 from the top of the fluid column (approximately 488 m below the surface) in the 1,262-m-deep Kilauea Volcano in Hawaii. Chemical analyses of these samples by Zablocki, Tilling, and B. F. Jones indicate that the waters are mildly saline and are of the sodium sulfate type and that seawater is not part of the hydrogeologic regime above the magma reservoir, as had been previously suggested by some investigators. Chemical and temperature data also indicate measurable dilution effects (lower salinity and temperature) in a sample collected the day after a period of high rainfall.

Silica diagenesis

Diagenetic cristobalite is widely present in the Monterey Shale of the Templer Range, Calif., and its d_{101} spacing contracts from 0.411 to 0.404 nm with increasing depth of burial. Lines of constant d_{101} spacing, derived by contouring many determinations of the spacing over a given area, represent virtually horizontal, isothermal surfaces that prevailed in the original pile of sediment.

K. J. Murata and R. G. Randall (1975) tested the possible use of the spacing in structural studies by X-raying 100 samples of cristobalitic porcelanite from an area near Taft. They found that the lines of constant d_{101} spacings accurately delineated the folded structure of the Monterey Shale.

Saline environments

Further treatment of previously published data and 87 new solution analyses from the Lake Magadi area, Kenya, have extended information on the chemical evolution of alkaline saline waters. According to B. F. Jones, the dominant influence of evaporative concentration has been documented by constant chloride to sodium and chloride to bromine ratios. The new data also show the loss of fluorine, boron, and sulfate, as well as alkaline earth, silica, potassium, and total carbonate during the concentration process. The greatest compositional changes probably are caused by evaporation to dryness and only partial re-solution. Calculations suggest that all water compositions in the Magadi system can be derived through proportional mixing of dilute inflow with lake-surface brines at various stages of development.

L. N. Plummer (1975) reported that the effect of mixing seawater or saline subsurface water with fresh calcium-carbonate type ground water was evaluated theoretically, by use of the computer program, MIX2. The results document the amount of subsaturation of calcite in mixtures and show the dependence of the mixing effect on partial pressure of carbon dioxide, temperature, ionic strength, de-

gree of saturation with respect to calcite, and pH of end-member solutions prior to mixing. The mixing calculations define geochemical environments that favor (1) development of increased porosity and permeability in limestone aquifers, and (2) freshwater dolomitization of calcium carbonate by replacement.

Gases in ground water

Methane, propane, and ethane.—Partial pressures of dissolved gases were determined for 17 samples of ground water from major aquifers of the northern Great Plains. These include samples from several members of the coal-rich Fort Union Formation and from underlying Cretaceous aquifers.

D. W. Fisher and M. G. Croft found that nitrogen to argon concentration ratios in these waters exceed the calculated value for air-saturated recharge. The increased ratios probably result from release of nitrogen during the course of degradation of organic matter in the formations. Nitrogen and argon pressures determined for two samples from flowing artesian wells were substantially lower than the corresponding calculated values for air-saturated recharge water. However, methane partial pressure in each of these waters was greater than 100,000 Pa. Apparently rapid evolution of methane from the discharging wells has stripped some of the dissolved air gases from the formation. This stripping effect was not evident in other water samples, although two of them contained methane at comparably high pressures.

The range of methane pressures determined was from about 500 Pa to more than 200,000 Pa; all of the high values were for samples from the deeper Cretaceous aquifers. Three of these waters contained measurable quantities of ethane, and one sample from a 190-m deep well had a detectable propane content. Sulfate concentrations were less than 150 mg/l in all samples with more than 10,000 Pa methane pressure; however, the inverse correlation is not regular. In contrast, sulfate in shallow Fort Union water often exceeds 600 mg/l, whereas observed methane pressures in the uppermost aquifers are less than 5,000 Pa.

Ammonia.—Although ammonia, as N, is barely detectable in most ground water pumped in the Central Platte Natural Resources District, Nebr., significant concentrations evidently percolate to the ground-water reservoir. L. R. Petri and R. A. Engberg reported that ammonia concentrations ranging from 0.64 to 3.9 mg/l were detected in the upper 30 cm of ground water at 10 study sites in late winter or early spring of 1974.

The ammonia that reaches the water table evidently is oxidized to nitrate at rates that depend somewhat on soil permeability. Where soil permeability is high, concentrations in the upper 30 cm of the ground-water reservoir gradually diminished only slightly from spring to summer and persisted throughout the year.

Carbon dioxide.—The hydrogeochemistry of Bermuda ground water was studied by L. N. Plummer (USGS), H. L. Vacher (Washington State Univ.), F. T. MacKenzie (Northwestern Univ.), O. P. Bricker (The Johns Hopkins Univ.), and L. S. Land (Univ. of Texas) in order to clarify the chemical processes active during phreatic diagenesis of Pleistocene carbonate sediments. The three processes that control the chemistry of Bermuda ground water are (1) generation of elevated CO_2 partial pressures in soils and marshes, (2) dissolution of metastable carbonate minerals (principally aragonite), and (3) mixing with seawater. Nonequilibrium dissolution and precipitation reactions coupled with seasonally variable fluxes of CO_2 to and from the ground water are important in accounting for the carbonate mineral formation.

Kinetics of calcite solution

L. N. Plummer followed the dissolution of Iceland spar in CO_2-saturated solutions at 25°C and 101,325 Pa total pressure by measurement of pH as a function of time. Surface concentrations of reactant and product species were calculated from bulk-fluid data using mass-transport theory and are near bulk-solution values, demonstrating that calcite dissolution under the experimental conditions is controlled by the kinetics of surface reaction. An empirical-rate relationship was developed and applied to predicting the rate of calcite dissolution in natural environments.

STATISTICAL GEOCHEMISTRY AND PETROLOGY

Q-mode factor analysis

Continuing investigations by A. T. Miesch of the application of an extended form of *Q*-mode factor analysis to problems in geochemistry and petrology led to the concept of compositional structure in igneous rock bodies. The compositional structure of a body is reflected by the quasi-rank of a representative matrix of chemical or mineralogic data. The quasi-rank of the data matrix is low, and the compositional structure of the body is simple, if the

matrix is similar to a matrix of low true rank. Use of this method means that the major features of compositional variation and covariation in the body can be explained by the mixing or unmixing of relatively few end-members; that is, the igneous body probably formed by a relatively simple combination of processes. Simple compositional structures have been found in (1) a rhyolite-basalt complex in Yellowstone National Park, Wyo., (2) lavas and pumices from the 1959 summit eruption at Kilauea, Hawaii, and (3) granitic batholiths of the Sierra Nevada, Calif., and the Alaska-Aleutian Range.

Complex compositional structures occur in rock bodies that acquired their compositional variation largely by complex combinations of processes, such as those that operate in magmatic differentiations. Complex structures have been identified in several igneous bodies, including the Pikes Peak batholith in Colorado, a recent basalt flow in New Mexico, and the layered series of the Skaergaard intrusion, Greenland.

Some of the above investigations and the methods used were described by Miesch (1975a, b), and a computer program was published by Klovan and Miesch (1975).

Whether the compositional structure of the igneous body is simple or complex, petrologic models can be developed by searching for end-member compositions. Commonly, the end-member compositions are those of mineral species within compositional systems such as albite-anorthite, forsterite-fayalite, or wollastonite-enstatite-ferrosilite. The end-member compositions may also be those of mineral clusters such as, for example, those in the system quartz-orthoclase-albite-anorthite. Compositions within two-, three-, or four-component systems can be systematically examined for compatibility with the compositional variation in an igneous body by using a new computer program, QSCAN, and compatible species may constitute end-members for petrologic models. Commonly, QSCAN identifies mineral species actually present in the igneous body, as determined by conventional petrologic methods. In other applications, QSCAN has pointed to compositions of minerals that may have been early differentiates or of materials that might have been incorporated into the primary magmas.

Simulation of sampling problems

A new interactive computer program, SAMPLE, was prepared by A. T. Miesch for the simulation of sampling problems encountered in either geochemical exploration or general geochemical surveys. The purpose of the program is to observe the effects of random errors in sampling and analysis on efforts to detect geochemical anomalies or regional trends. The results are providing guidelines for judging the required sampling density and analytical precision for sampling programs.

Geochemical discriminant for sandstones

J. J. Connor and N. M. Denson reported that samples of sandstone near the Fort Union-Wasatch contact in the Powder River Basin have been successfully assigned to their respective stratigraphic position by using a discriminant function based on bulk chemical composition. The following discrimination index has correctly classified 81 of 99 sandstone samples collected near the Fort Union-Wasatch contact around its outcrop belt:

$$Z = 2.38 \log \mathrm{Fe} + 2.09 \log \mathrm{Mn} + 4.29 \log \mathrm{Ba} + 0.89 \log \mathrm{Na}$$

A sandstone sample can be classified if its bulk concentrations of iron and sodium (in percent) and manganese and barium (in parts per million) are known. Any sample having an index (Z) above 14.92 is assigned to the Wasatch Formation, and any sample with an index less than 14.92 is assigned to the Fort Union Formation. This index correctly classified 26 of 27 samples that were not used to define the index. The samples were collected from the Wasatch Formation near the contact with the Fort Union in northern Campbell County, Wyo. Three sandstone samples from the lower part of the Fort Union and four more from the underlying Lance Formation were tested by the discriminator and found to be chemically similar to the Wasatch. All of these results support previous work (Denson and Pipiringos, 1969) based on heavy mineral suites and confirm the suspicion that sandstones in the upper part of the Fort Union Formation are distinct from those in the lower part of the Wasatch Formation, the Tullock Member of the Fort Union, and the Lance Formation.

ISOTOPE AND NUCLEAR GEOCHEMISTRY

ISOTOPE TRACER STUDIES

Source and history of island-arc magmas

Samples from the basalt, andesite, dacite, and rhyolite suites of Rabaul and Talasea, New Britain, were studied for rare-earth content by J. G. Arth and for strontium isotopic composition by Z. E. Peterman. The $^{87}Sr/^{86}Sr$ ratios in both suites are

nearly constant, averaging 0.7037 for Rabaul and 0.7035 for Talasea. The chondrite-normalized rare-earth patterns for both suites are relatively flat and show increasing concentrations from basalt to dacite. Europium anomalies are not found in phenocryst-poor basalt and are increasingly negative from basaltic andesite to rhyolite. The data are compatible with a model for the origin of the basaltic magmas by 20 to 30 percent melting of mantle peridotite and a model for the origin of the basaltic andesites, andesites, dacites, and rhyolites by fractional crystallization of olivine, pyroxene, plagioclase, and opaques in varying proportions from the basalt magmas. The trace-element and isotopic characteristics of both suites are not consistent with an origin by melting of subducted oceanic crust.

Genesis of Boulder Creek Granodiorite

A study of regional variations in the trace-element and strontium isotopic composition of granodiorites of Boulder Creek age (1.7 b.y.) in Colorado was started by C. E. Hedge. Thus far, samples from central Colorado have higher rubidium, strontium, and barium contents and more fractionated rare-earth patterns than samples to the north and south. The differences are thought to reflect differences in source materials and genetic processes. Tentatively identified processes include anatexis of amphibolite and metagraywacke and fractional crystallization of mantle-derived mafic magma. The inferred processes are distinct from those that could be expected in any simple Cenozoic tectonic analog. Any tectonic model must explain the generation of large volumes of magma over a broad area and within a brief span of geologic time.

A two-stage model for terrestrial lead-isotope evolution

J. S. Stacey proposed a two-stage model for terrestrial lead-isotope evolution. This construct utilizes the solar system age of 4.57 b.y. and the composition of primordial lead determined by Mitsunobu Tatsumoto, along with the recently determined values for the half-lives of uranium. The model allows the ages of many "volcanic exhalative" lead-ore deposits to be approximated by their lead-isotopic composition to within ±50 m.y. of their known age by other methods.

Lead-isotopic composition in basalts and sediments from the Nazca Plate

Lead-isotopic compositions and uranium, thorium, and lead concentrations have been determined by Mitsunobu Tatsumoto and Dan Unruh in 11 basalt and 3 sediment samples from leg 34 of the DSDP. The $^{232}Th/^{238}U$ ratios and the lead-isotopic composition of the basalts are typical of oceanic tholeiites and suggest that the magmas were extruded at the extinct Galapagos rise. Lead-isotopic compositions, when corrected for in-place uranium decay, are similar for all basalt samples analyzed. The similarity suggests that the magmas originated either from a portion of the mantle in which lead-isotopic composition is homogeneous or from one in which partial melts from different sources have been mixed in the same proportions for the last 45 m.y.

The lead concentration in a sample of Pliocene sediment is about average for deep-sea sediments but about 10 to 20 times higher than that of samples of lower and middle Miocene sediments. The low lead concentration in the Miocene sediments can be attributed to carbonate accumulation. The similarity of the lead-isotopic compositions in sediments and basalts supports a hypothesis that the metallic elements in the metalliferous sediments of the Nazca plate are of ocean-ridge origin.

STABLE ISOTOPES

Berridale batholith, Australia

Two contrasting types of Paleozoic granitoids occur widely in southeastern Australia and can generally be distinguished by their chemistry, mineralogy, field occurrence, and initial strontium isotope ratios. Previous work has shown that the granitoids are derived by partial melting of two different types of source materials: (1) Igneous or "I type" and (2) sedimentary or "S type."

J. R. O'Neil (USGS) and B. W. Chappell (Australian National Univ.) measured oxygen and hydrogen isotope compositions on 59 whole-rock samples of fresh and altered granitoids and xenoliths. For S-type plutons, average δO^{18} values range from 9.9 to 10.5, whereas for the I types the range is 7.9 to 9.4. Xenoliths are about 1 per mil lighter in O^{18} and generally heavier in deuterium than the host rocks. The average δD values (and water contents) are -62 ± 4 (1.10 percent) and -77 ± 12 (-0.73 percent) for S and I granitoids, respectively. Individual δD values range from -52 to -108 and correlate very well with water content: the more water-rich the melt, the greater the deuterium content. This effect must be related to the physical and chemical conditions of the ascent and crystallization history of the granitoids.

The rather large ΔO^{18} (quartz-biotite) values range from 5.0 to 6.9 (independent of type) with a mean of 6.0. Thus, typical isotope temperatures

of ~520°C are inferred and may be retrograde effects.

O^{18} compositions of trondhjemites

Fred Barker, Irving Friedman, and J. D. Gleason analyzed the O^{18} composition of whole-rock samples of 75 Precambrian and Phanerozoic trondhjemites and acidic metavolcanic gneisses of 19 cogenetic mafic to intermediate rocks from North America, Fennoscandia, and southern Africa. Trondhjemites, metadacites, and metarhyodacites (average contents of 72.2 percent SiO_2 and 1.93 percent K_2O) that probably are isotopically undisturbed give an average δO^{18} of +7.2 per mil and a range of +5.5 to 8.3. The mafic to intermediate rocks show a wide range of values, the extremes of which indicate exchange during or after emplacement with either isotopically light meteoric waters or isotopically heavy wall rocks but which in part show relatively undisturbed δO^{18} values of +4.5 to 5.5 per mil. The δO^{18} values of the trondhjemites and compositionally similar metavolcanic rocks, which are definitely lower than those of most granites and quartz monzonites, are in accord with the several models of derivation of these rocks from basaltic parents by partial melting or igneous differentiation.

Fossil thermal gradients in the Ruby Mountains

The K-Ar and Rb-Sr mineral ages in crystalline rocks in the northern Ruby Mountains, Nev., are less than the ages of the host rocks. Oxygen and hydrogen isotopic compositions of all the dated minerals and quartz have been determined.

R. W. Kistler and J. R. O'Neil interpreted the reduced mineral ages to reflect cooling during uplift, along an arch of regional extent with a trend of about N. 30° E., that began during emplacement of the 36-m.y.-old Harrison Pass pluton into the central part of the range.

Petrologic data indicate that the exposed crystalline terrane was at depths that ranged from about 13 to 8 km prior to uplift and erosion 36 m.y. ago. Temperatures from top to bottom in this depth interval at the beginning of uplift are estimated to have ranged from 350° to 560°C on the basis of the critical temperatures required to permit complete retention of radiogenic daughter products in the minerals dated. Oxygen isotope geothermometry indicates oxygen equilibration temperatures that ranged from 400° to 650°C from top to bottom of the same depth interval. The thermal gradient indicated by the oxygen isotopic data closely approximates the thermal gradient that must have existed during Mesozoic amphibolite-facies metamorphism of the crystalline terrane.

Magmatic or meteoric water in ore fluids

Studies by R. O. Rye (USGS), G. P. Landis (Univ. of New Mexico), and F. J. Sawkins (Univ. of Minnesota) on the hydrogen and oxygen isotopic composition of numerous Tertiary hydrothermal ore deposits in the Andes of South America indicated that magmatic fluids are nearly always present at some stage during the history of the hydrothermal fluids. The hydrothermal fluids in these Tertiary ore deposits are probably not dominated by meteoric waters, as are those in similar deposits in the Western United States, because of the relatively dry climate in the Andes during ore deposition. The study suggests that the dominance of meteoric water in the hydrothermal fluids of certain ore deposits may be related to local climate and hydrology rather than to anything fundamental about ore deposition.

Copper Canyon deposit

J. N. Batchelder found that the fluid-inclusion water in quartz from the Copper Canyon deposit at Battle Mountain, Nev., has δD values that range from −101.5 to −75.6 per mil. The calculated δO^{18} of water from quartz ranged from +3.1 to 10.9 per mil. The calculated δD for water (from biotite analyses) ranged from −71.2 to −111.5 per mil, and the calculated δO^{18} of water from biotite ranged from +0.5 to +5.0 per mil. These data indicate that the ore-forming solutions were most likely composed of magmatic water mixed with significant amounts of meteoric water.

Antarctic climates

Irving Friedman and G. I. Smith showed that $CaCl_2 \cdot 6H_2O$ (antarcticite) grown at −20° to −30°C is enriched in O^{18} by 11.3 per mil and depleted in D by 16 per mil relative to the solution.

With this information, it is possible to explain the anomalous isotopic composition of the brines of Don Juan Pond, Victoria Land, Antarctica. It is also possible to explain the brine composition in nearby Lake Vanda and to decipher the climatic history of this interesting warm lake located 528 km from the South Pole as follows: (1) Fjord formed 75 m.y. ago during warm Antarctic climate; (2) fjord blocked, trapping sea water ~50,000 yr ago; (3) sea water evaporated, climate cooler than present, desiccation yielded $CaCl_2 \cdot 6H_2O$ crystals, winds blew NaCl and $MgCl_2$ away; (4) brief climatic warming occurred 2600±200 yr ago, climate slightly warmer

than present; (5) climate cooled and lake desiccated again; (6) another climatic warming occurred about 1,000 yr ago, initial warming slightly warmer than at present.

The present high temperature (25° to 28°C) in the lower part of this saline lake is due to solar heating, not geothermal heating.

Climate and deuterium in tree rings

Irving Friedman made deuterium analyses of wood (tree rings) from bristlecone pine collected from the White Mountains, California-Nevada. The variation in δD appears to correlate with the European climate from 200 A.D. to 1950. There are some specific points that do not show an exact correlation, and this discovery may be important to theories of climatic change. Additional work is now underway on living trees to determine the relationship between the δD of tree wood and known climatic factors.

Growth of oats in light water

While growing oats from seeds in closed jars, Irving Friedman and J. D. Gleason observed that seeds growing in water from the Antarctic and depleted in O^{18} and deuterium grew much more rapidly than seeds growing in water of more normal isotopic composition. This observation was confirmed in several sets of experiments conducted at different temperatures.

ADVANCES IN GEOCHRONOMETRY

Thermoluminescence dating technique for Hawaiian basalts

A technique for dating young Hawaiian basalts using thermoluminescence (TL) was developed by R. J. May. The basic method, which has been used for radiation dosimetry in health physics and for age measurements in archeologic studies, depends on the measurement of a very small amount of light emitted when dielectric crystals are heated in the laboratory. The amount of light given off by a sample is a function of the age of the sample, the natural radiation dose rate, and the "sensitivity" of the crystals.

The ages of alkalic basalts from the island of Hawaii can be reproduced to within about ±10 percent when they are compared with carbon-14 and K-Ar ages on the same lavas. The TL ages on tholeiitic basalts are less accurate, primarily because low elemental concentrations of uranium and thorium make these two important sources of natural radiation difficult to measure. The method, which appears to have a range of from about 5×10^3 to 5×10^5 yr, fills an important gap between the useful ranges of the carbon-14 and the K-Ar dating techniques and should be applicable to other igneous rock types.

Uranium-lead ages and open-system behavior of pitchblendes, Shirley Basin, Wyoming

Uranium-lead isotope apparent ages of several pitchblende and pitchblende-pyrite samples from roll-type uranium deposits of the Shirley Basin district, Wyo., were determined by K. R. Ludwig, and all have been found to be moderately to very strongly discordant. The discordance and variability of apparent ages, even from clearly cogenetic and closely spaced samples, show that isolated uranium-lead analyses of roll-type pitchblende samples can be misleading. The pitchblende samples have lost both lead (greater than 40 percent for some samples) and ^{238}U intermediate daughters such as ^{222}Rn or ^{226}Ra (greater than 65 percent for some samples). Incorporation of an old radiogenic lead component by the pitchblende has not significantly altered the apparent ages. The oldest apparent ages, which are the least discordant, indicate that some of the uranium mineralization in the district began earlier than 34 m.y. ago.

Age of disseminated uraninite, Wheeler Basin, Colorado

K. R. Ludwig determined the isotopic ages of specimens, collected by E. J. Young, from the disseminated uraninite occurrence at Wheeler Basin, Grand County, Colo. Uranium and lead isotopic analyses of monazite and uraninite indicate that these minerals formed 1,446±20 m.y. ago. This time correlates well with the intrusion of the Silver Plume Granite. The uraninite and monazite were also affected by a later disturbance at 880±130 m.y. but show essentially no effects of subsequent events. This secondary disturbance may have been due to intrusion of dikes related to the Pikes Peak batholith, dated at 1,041±13 m.y. ago.

Problems in dating sericite

Potassium-argon dating of sericite, a common wall-rock alteration mineral in epithermal ore deposits, has been used to date alteration associated with mineralization. M. L. Silberman found, however, that the K-Ar ages of sericite may be anomalously high in host rocks that have a detrital mica component.

In two Nevada epithermal mineral deposits, sericite has yielded strongly anomalous ages of mineralization. In both cases, it is possible to establish limits

for the age of mineralization from geologic field relationships. In both cases, sedimentary rocks, in which mica occurred as a detrital component, were the host rocks.

Fluid-inclusion filling temperatures indicate that temperatures of 200° to 300°C are reached in hydrothermal fluids in epithermal ore deposits. Evidently, these temperatures are not high enough or do not persist for long enough time periods to release all prealteration radiogenic argon from muscovite during a typical hydrothermal event, despite severe alteration of the host rocks.

Dating early Pleistocene men by the uranium-series method

B. J. Szabo (USGS) dated fossil bones associated with several Neanderthal man discoveries by means of the uranium-series method. K. P. Oakley (British Museum), supplied a tooth at Elephas Atlanticus that was associated with remains of the Ternitine man of Algeria. The tooth yielded a Th^{230} age of 210,000±35,000 yr. Correction for a small amount of excess Pa^{231} would indicate an open-system age of 180,000±40,000 yr.

Bone samples from several Neanderthal man localities in Great Britain were furnished by D. Collins (University of London). The Swanscombe man was apparently reliably dated at 300,000 yr, but samples from the Stutton and Brunden localities yielded only open-system ages of 125,000±20,000 and 174,000±30,000 yr, respectively.

Geochronology in Indonesia

Some 35 samples from Indonesia, dominantly from Sulawasi and Sumatra, were dated by J. D. Obradovich in cooperation with P. W. Richards, W. H. Nelson, and the late D. E. Wolcott. The work on Sulawasi (formerly Celebes Island) has been restricted to the southwestern arm where basaltic volcanism commenced on a pre-Cretaceous basement 17 to 18 m.y. ago. This activity was followed by a period of voluminous andesitic volcanism 9 m.y. ago and lesser amounts of dacitic eruptions 4 to 5 m.y. ago. Andesites that appear to be of Holocene age occur at the southernmost end of the southwestern arm. Plutonic activity (dioritic to granitic) spans a period of some 9 to 10 m.y. from ~14 to 5 m.y. ago. The largest exposed granitic body near Madjene was dated at 6.2 m.y. However, one of the few shows of mineralization in this region is associated with a nearby but much smaller and younger body dated at 5.5 m.y.

Sampling in the northern part of Sumatra was restricted primarily to the numerous granites that crop out along the western margin, although a few samples of upper Cenozoic andesites and tuffs were collected.

The oldest granite found so far is from a small outcrop exposed along the easternmost fault boundary of Lake Singkarak. The K-Ar age of ~290 m.y. on muscovite must be considered simply a minimum, since the granite shows east-west segregation bands and north-south fracture system. Although other Sumatran granites have been reported to be of Permian and Carboniferous age or older, this geochronometric confirmation is the first.

Two large granitic masses, one at and to the east of Sibolga and the other east of Sisawah, indicate a period of Triassic plutonism ~210 to 215 m.y. ago.

Late Triassic-earliest Jurassic plutonism (~190 m.y. ago) is indicated just to the east of Kutanopan. The pluton to the east of Singaimas (northeast of Lake Singkarak) was emplaced in the latest Jurassic (~145 m.y. ago).

The Lassi Granite (southeast of Lake Singkarak) may be another of latest Jurassic or earliest Cretaceous age; however, the large analytical uncertainty of its age currently precludes any definitive statement. The same can be said for the large granite mass ~25 km to the southeast of Sawahlunto. Preliminary data indicate a possible age range of 110 to 155 m.y.

A small granite body of middle Cretaceous age (105 m.y.) north of Kutanopan seems to be the youngest intrusive mass along the western margin except for a granite ~11 km south of Padangpandjang, which yields an age of ~8 m.y. However, this granite body sits in the midst of the young andesitic volcanic field, and the age of 8 m.y. may reflect thermal resetting. The geologic constraints of the post-Permian and pre-Late Cenozoic do little to solve this problem.

Two of the upper Cenozoic andesites, one south of Solok and the other from the caldera rim around Lake Manindjau, were dated at 1.66 and 0.80 m.y., respectively. The age of 0.80±0.20 m.y. places a lower limit on the age of the nearby but demonstrably younger andesitic volcanoes of Singgalang, Tandikat, and Marapi. Although Tandikat and Marapi have a record of historic eruption, only Marapi has active fumaroles.

Uranium-series dating of marine deposits

Recent drilling and trenching by the Department of Defense on Eniwetok Atoll provided excellent samples of coral for dating by the uranium-series

method. Four samples from two cores, supplied by J. I. Tracey, Jr., were dated by B. J. Szabo. Three and possibly five unconformities are recognized in these cores. These unconformities are related to periods of coral growth during the warm cycle and higher sea level of the interglacial period, which was followed by a lowering of the sea level at the onset of glaciation and subsequent erosion of the upper surfare of the reefs.

A sample taken from hole PAR-16 at a depth of 7.9 m, just above the upper unconformity, has a Th^{230} date of 8,700±500 yr, which appears reliable because the U^{234}/U^{238} ratio of 1.14±0.01 is concordant for that age. A second sample from that hole taken at a depth of 9.9 m, just below the upper unconformity, yielded an age of 130,000±7,000 yr. A sample from hole PAR-15 at a depth of 14.9 m, between the upper and next lower unconformity, also has an age of 130,000±7,000 yr. The U^{234}/U^{238} ratios of 1.12±0.01 and 1.10±0.01 indicate that these samples remained closed with respect to uranium and thorium isotopes and that these ages are reliable.

These data show that a hiatus in coral growth of about 120,000 yr duration can be observed because, during that time, the level of the ocean did not rise enough to submerge the reefs and allow coral growth. If it is assumed that there was no unaccountable uplift during this interval, these dates define the last major glacial period in this region of the Pacific, which occurred from about 130,000 to 9,000 yr ago.

An additional sample from hole PAR-15 at a depth of 38.7 m, just below the third or possibly the fourth unconformity, did not yield suitable age results. The sample apparently underwent both dissolution of some aragonitic structure and calcitic infilling. The Th^{230} date of 165,000 yr can be considered only as a minimum age; the age calculated from the measured U^{234}/U^{238} ratio (1.04±0.01) of 460,000±100,000 yr can be considered as a maximum.

Five coral and five shell samples from the Falmuth Formation of Jamaica have been dated; the samples were collected from three localities by W. Moore (U.S. Naval Oceanographic Office) along the north shore of Jamaica. The marine terrace is distinct, with an elevation above sea level up to 10 m. Only one of the corals yielded concordant Th^{230} and Pa^{231} dates of 129,000±10,000 yr. For the other four corals, open-system dates were calculated. The average of the five dates, 130,000±7,000 yr, appears to be a reliable age for the Falmuth Formation of Jamaica. Two of the shell samples yielded concordant dates (but ages that were too young) of 70,000 and 95,000 yr, respectively; however, these results do not agree with the dates for the coral samples. One shell yielded an open-system date of 137,000±20,000 yr that is in agreement with the average date of corals. The other two shell samples showed evidence of extensive migration of uranium isotopes and their long-lived daughter elements; thus, no ages could be calculated for these samples.

Uranium-series dating of fossil shells and bone was completed on material supplied by L. M. Gard, Jr. The results yielded an average age of 127,000±8,000 yr for the fossiliferous deposit of the South Bight II marine transgression at Amchitka Island in the Aleutian Islands. These Pleistocene beds were deposited during an interglacial high-sea stand contemporaneous with the well-dated period of coral reef formation on Hawaii and Barbados about 125,000 yr ago and with our more recent dates of about 130,000 yr for coral reef formation on Jamaica and Eniwetok.

GEOTHERMAL SYSTEMS

Magma beneath Yellowstone National Park

Geophysical and geological data gathered by the USGS over the past 10 yr confirm the 1911 hypothesis of R. A. Daly that a body of magma lies at moderately shallow depth beneath Yellowstone National Park (Eaton and others, 1975).

The Yellowstone Plateau volcanic field is less than 2 m.y. old, lies in a region of intense tectonic and hydrothermal activity, and probably has the potential for further volcanic activity. The youngest of three volcanic cycles climaxed 600,000 yr ago with an immense ash-flow eruption and the collapse of two contiguous cauldron blocks. Intracaldera doming 150,000 yr ago, voluminous rhyolite extrusion as recently as 70,000 yr ago, and the present-day high convective heat flow suggest a new magmatic insurgence.

The existence beneath the Quaternary rhyolite plateau of a body composed at least partly of magma is supported by the following evidence: (1) A major gravity low with steep bounding gradients, (2) an aeromagnetic low possibly indicating the existence of material above the Curie temperature at shallow depth, (3) substantial delays in the *P* velocity of seismic waves passing beneath the plateau, and (4) minor seismicity within the caldera, compared to a high level of seismic activity in some adjacent areas. The gravity low that extends beneath a postglacial arcuate fault zone just northeast of the Yellowstone

caldera suggests that the magma extends under the Tertiary volcanic rocks in that area.

Origin of spring and geyser vents in Yellowstone National Park

G. D. Marler and D. E. White completed a report on Seismic Geyser and its bearing on the origin and evolution of geysers and hot springs in Yellowstone Park. Seismic started as a fracture resulting from the Hebgen Lake earthquake of August 17, 1959. Over the next 5 yr, the fracture evolved through the progressive stages of a new fumarole, a small spouter, then a small geyser, and finally a large geyser erupting to 15 m in height. Its channel in the meantime had evolved from a narrow crack to a vent 12 m in diameter and with a probed (minimum) depth of 6.4 m.

The formation and evolution of Seismic, along with the results of research drilling (White and others, 1975), provide the keys for understanding the origin of craters and vents of other geysers and probably also of the large smooth-walled pools. New fractures result from vigorous seismic disturbance of large high-temperature convection systems with fluid pressure gradients 10 to 50 percent above hydrostatic. Near-surface enlargement of vents results from flashing of water to steam in partly cemented sinter and sediments; typical volume increases of the fluid phases are 75 to 150 times the initial liquid water volume (at 125° to 150°C) when erupted to atmospheric pressure. Deeper enlargement of the channel and local reservoir of each geyser probably occurs because of extreme pressure gradients probably locally much above the lithostatic gradient. Fountain-type geysers such as Seismic form where near-surface rocks are incompetent enough to produce an upward-flaring vent as decompression occurs and as wall materials are fragmented and ejected. Cone-type geysers probably form where near-surface rocks are relatively competent and resist extensive fragmentation; most erupted water drains away from the vent as SiO_2 is deposited locally to form cones or mounds.

Giant hydrothermal explosion crater in Yellowstone National Park

Evidence of a gigantic hydrothermal explosion on the northeastern margin of Yellowstone Lake was found by G. M. Richmond. The explosion deposit forms a hemielliptical ridge as much as 18 m high that encloses an area about 4.8 km long northeast of Mary Bay and about 2.4 km inland from the bay. The deposit consists of large and small angular slabs and chips of silica-cemented lake sand, silt, and till in an unsorted matrix of sandy, silty clay. Some rounded pebbles and cobbles, including a number of glacial erratics, also occur in the material.

The explosion deposit overlies lake sand or varved silt underlain by till of the last glaciation; all three are locally silica cemented. The outer margin of the deposit intrudes a thin organic lake-bottom sediment, carbon-14 dated by Meyer Rubin as 13,650± 650 yr old (W2894). The deposit is overlapped by fine lake sand containing near its base a thin layer of volcanic ash identified by R. E. Wilcox as the 12,000- or 12,600-yr-old Glacier Peak Ash, or possibly the St. Helens J. Ash. Charcoal 2 m above the ash has been carbon-14 dated by Rubin as 10,900± 350 yr old (W2736). Muffler and others (1971) have suggested that a sudden lowering of hydrostatic pressure would touch off a hydrothermal explosion and that such a lowering could be brought about by rapid draining of a lake. The sudden release of an ice-dammed lake that existed in the northern part of the Yellowstone Lake basin at that time probably caused the explosion.

Yellowstone's deep plumbing

New studies of Yellowstone hot-spring waters by A. H. Truesdell, R. O. Fournier, W. F. McKenzie, and Manual Nathenson were made by using geothermometer methods capable of indicating the temperatures of progressively deeper parts of geothermal systems (silica and cation geothermometers, mixing model calculations, and the sulfate-water isotope geothermometer). These investigations, combined with the recent geophysical evidence that the Yellowstone caldera may be underlain with magma at shallow (10 km?) depths, suggest that the caldera contains an extensive aquifer with hot (370±°C), moderately saline (1,000 ppm NaCl) water that escapes upward where suitable fractures exist. Many relatively small and cooler reservoirs exist in the shallow parts of the hydrothermal system. Although the residence time of water within these reservoirs is variable, the overall rate of upward flow between reservoirs and to the surface is rapid. The chemistry of the ascending waters is altered by dilution, reaction with rocks, and steam separation. The highest temperature likely to be attained by dilute convecting vapor-saturated water is about 370±°C because heating to slightly higher temperatures induces very substantial increases in volume (30 percent increase between 370° and 374°C). Thus, convecting fluid near the critical point may serve to regulate temperatures in deep geothermal systems.

Geothermal reservoir temperatures estimated from the oxygen-isotope composition of dissolved sulfate and water from hot springs

The O^{18}/O^{16} and D/H ratios of waters and O^{18}/O^{16} ratios of dissolved sulfates from hot springs were determined in six major geothermal systems in Yellowstone National Park, Wyo., by W. F. McKenzie and A. H. Truesdell. Values of $\delta O^{18}/(H_2O)$ varied with chloride content, but δO^{18} (SO_4^{-2}) was nearly constant (-12 ± 1 per mil relative to SMOW) for most waters studied. Steam-loss and mixing models were used to estimate the O^{18}/O^{16} ratio of the deep reservoir water for each system. The residence time of dissolved sulfate in the deep reservoir is sufficient to ensure isotopic equilibrium between dissolved sulfate and water, and waters ascend to the surface rapidly in relation to the rate of isotopic exchange. Except for waters containing sulfate of surficial origin, calculated temperatures of last sulfate-water isotopic equilibrium ranged from 320° to 420°C for all geothermal areas within the Yellowstone caldera. These temperatures are higher than those indicated by other geothermometric methods.

Calculation of deep reservoir temperatures from chemistry of boiling hot springs of mixed origin

Geothermometers based on the contents in hot springs of SiO_2, Na, K, and Ca are successful in indicating subsurface temperatures below 200° to 300°C. For higher temperatures, reequilibration usually occurs during passage of the water to the surface. If hot and cold waters mix in the subsurface, indications of maximum temperatures may be preserved. Computations based on the chemistry of mixed springs of less than 80°C have been previously described by Fournier and Truesdell (1974).

A new method was devised by A. H. Trusdell and R. O. Fournier to calculate deep temperatures and hot-water fractions for mixed springs that issue at boiling temperatures. In the following equations, Cl is the chloride content; H_w, H_s, and H_{ws} are specific enthalpies at the surface temperatures of water, steam, and evaporation, respectively; H_{sil} is the enthalpy of liquid water at the temperature indicated by the silica geothermometer; and the superscripts *m*, *n*, and *c* indicate mixed, nonmixed, and cold springs, respectively. The parameters H^h and X are the specific enthalpy and mass fraction of the hot component of the mixed water:

$$X=\frac{Cl^m H_{ws}^n (H_s^m - H_{sil}^m) + Cl^m H_{ws}^m (H_{sil}^m - H_w^c) - Cl^c H_{ws}^n H_{ws}^m}{Cl^n H_{ws}^m (H_s^n - H_w^c) - Cl^c H_{ws}^n H_{ws}^m}$$

$$H^h=\frac{H_{sil}^m - H_w^c}{X}+H_w^c$$

Temperatures are determined from specific enthalpy by reference to standard steam tables. The method has successfully predicted observed deep temperatures for drilled geothermal systems in New Zealand and Chile.

Geothermal modeling

To gain experience in solving multiphase flow equations, several one-and two-dimensional finite element and finite difference models were developed by J. W. Mercer, C. R. Faust, and G. F. Pinder and applied to the classical Buckley-Leverett problem of water flooding a petroleum reservoir. Using their experience from isothermal multiphase modeling, they developed and solved partial differential equations describing heat transport in a steam-water-rock system by means of a Galerkim finite element method. The final equations are in terms of the dependent variables pressure and enthalpy and are valid for flow of compressed water, steam-water mixtures, and superheated steam; thus, the numerical model is capable of simulating both hot-water and vapor-dominated geothermal reservoirs. The model also allows for phase changes and therefore can simulate the transition of a hot-water reservoir to a steam-water reservoir (for example, the Wairakei, New Zealand, geothermal field). Numerical tests have been successfully conducted; however, no field application has been attempted thus far.

Traces of deep saline brines in most subsurface dilute waters

D. E. White concluded that probably huge quantities of saline fluids of various origins have circulated through the "fossil" geothermal system of old hydrothermal ore deposits. The ore fluids, commonly ranging from 1 to 40 percent in dissolved salts, were generally being diluted by meteoric water during ore depositions and were eventually completely flushed by such water.

Deep saline waters of all kinds are eventually displaced as a general consequence of compaction, progressive metamorphism, and convective flushing related to igneous activity and may generally leave no obvious permanent record of their earlier passage such as recognizable ore deposits. Total volumes of such saline fluids are unknown but must be many thousands of cubic kilometres. An important consequence of this conclusion is that any water of low to moderate salinity is likely to have a small proportion of "deep" saline water, commonly of nonmeteoric origin. Chemical and isotopic criteria are

not yet precise enough to identify very small proportions of such waters, but characteristic "signatures" may eventually prove useful.

In recent years, many geochemists have explained the chemical compositions of subsurface waters as products of the interaction of meteoric waters with their associated rocks, without involving any saline component of "deep" or mixed origin. However, the common occurrence of ore fluids of high salinity and diverse origins and the evidence for dilution and eventual flushing of such fluids by meteoric water imply that most subsurface waters of moderate salinity are likely to be mixtures of saline and dilute waters.

Structural control of steam resources in The Geysers steam field, California

Comparison of recent geologic, geoelectric, and microearthquake data in the Geysers-Clear Lake area by R. J. McLaughlin and W. D. Stanley indicated that economically significant steam resources can be related to local fault-controlled structural traps in two areas. In one area of steam production near the Geysers Resort, extensive hydrothermal alteration and numerous microearthquakes are associated with N. 30°–40° W.-trending faults that dip steeply to the northeast. Evidence of recent fault activity, including tilted 750±105-yr-old steam deposits, reinforces a correlation of the fault zone with the microearthquakes. The association of the microearthquakes and the hydrothermal alteration is interpreted to indicate that rocks in the fault zone are saturated by a high column of hot water that overlies the steam reservoir.

A few kilometres southeast of the Geysers Resort, near Castle Rock Spring, steam production is from an area of anomalously low resistivity, also presumably due to rocks saturated by a structurally high column of hot water above the steam reservoir. The area underlain by these rocks of low resistivity is overlain by southeastward-dipping graywacke, basalt, and serpentinite and is bounded on the north and south by steep-dipping N. °80 W.-trending faults and on the east by steep-dipping N. 50° W.-trending faults.

SEDIMENTOLOGY

Sedimentology, the study of sediment 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 USGS are directed toward (1) solution of water-resource problems and (2) determination of the genesis of sediment and application of this knowledge to sedimentary rocks for more precise interpretation of their depositional environment. Many USGS studies involving sedimentology apply 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-resource problems involving water-sediment mixtures. Sediment is being considered more and more as a pollutant. Inorganic and organic sediment, transported by streams to sites where deposition takes place, carries major quantities of sorbed toxic metals, pesticides, herbicides, and other organic constituents that accelerate the eutrophication of lakes and reservoirs. 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.

VARIABILITY OF SEDIMENT YIELDS

Sediment yields of Ohio streams

P. W. Anttila and R. L. Tobin defined fluvial sediment yields and characteristics in Ohio, incorporating 5 yr of periodic data from 39 sites on natural-flow streams with current and historic daily sediment data from 12 streamflow stations. Extension of the daily sediment data to a 25-yr base period, 1946–70, showed that annual suspended-sediment yields in Ohio range from 54 to 185 t/km². The extended yields were determined by a least squares regression of the logs of annual suspended-sediment discharge with the log of the product of annual mean water discharge and the sum of annual peak-water discharge above a given base discharge. Standard errors of estimate for the regressions ranged from 12 to 36 percent.

Bedload, estimated by using Maddock's classification, was found to be less than 10 percent of the total annual suspended-sediment discharge for most streams.

Data from suspended-sediment particle-size analyses suggested a good correlation with soil types and State physiography. Clay content in excess of 80 percent was common in the northwestern quarter of the State, but decreased to slightly less than 50 percent in the eastern part of Ohio. Sand content gen-

erally represented less than 10 percent of the suspended sediment, averaging less than 5 percent in the northwestern part of the State and less than 15 percent in the Appalachian Plateau in the southeastern part of the State.

Estimates of sediment yield in the Arkansas River basin, Kansas

W. R. Osterkamp's studies of sediment yields in the Arkansas River basin of Kansas led to development of a method of estimating sediment yields from unsampled basins. Average slope is determined from topographic maps, and average runoff is measured; runoff is interpolated from data for nearby basins if discharge data are otherwise unavailable. A normal sediment yield is determined from an empirically derived curve that relates average annual sediment yield to mean runoff. The estimated yield for the basin is adjusted by applying an exponential power of the slope.

Preliminary comparisons of estimated sediment yields with actual yields determined from suspended-sediment samples indicate that runoff and slope are primary determinants of sediment yield. Geologic variations generally seem to cause only minor differences, whereas land-use practices, hydraulic structures, and other man-induced changes have significant effects.

Sediment discharge in the Umpqua River basin

Annual sediment yields in the central and upper parts of the Umpqua River basin, Oreg., range from less than 105 to 700 t/km². Results of studies by D. A. Curtiss (1975) showed that the lowest yields are from the Upper Cow Creek, Olalla Creek, and South Umpqua River in the southern part of the basin. Yields are greatest from Lookingglass Creek and the South Umpqua River below the mouth of Cow Creek in the central part of the basin. That area is characterized by cultivated broad alluvial valleys, whereas the upstream areas are essentially forested. Sediment yield from the North Umpqua River basin is moderate, 214 t/km² from a 3,480-km² area, much of which is forest.

Sediment yields of Minnesota streams

Estimates of the annual suspended-sediment yield and of the expected range of suspended-sediment concentrations were made for rivers in Minnesota. These estimates by C. R. Collier (1974) were based on 4 yr of record of 21 daily or periodic stations on 18 rivers throughout the State.

Estimated annual sediment yields range from 0.7 to 7 t/km² in the forested northeastern and north-central lake regions of the State, 14 to 42 t/km² in the lower Minnesota River basin in the south-central part, to more than 175 t/km² in the extreme southeastern part. Peak suspended-sediment concentrations during storm runoff seldom exceed 500 mg/l in most northern streams but may approach 10,000 mg/l in southeastern streams. During periods of uniform flows, suspended-sediment concentrations are generally less than 50 mg/l in the northern streams compared to nearly 200 mg/l in the southeastern streams.

Sediment yields high in Oregon coast streams

Sediment yields from 13 streams along the central Oregon coast range from moderate to high, according to Antonius Laenen and F. J. Frank. The 13 streams drain basins on the western slope of the Coast Range and vary in size from 4.7 to 865 km². The smallest sediment yield, about 80 t/km², was from Beaver Creek, which drains an area of 37 km². The highest yield, nearly 490 t/km², was from Drift Creek, which drains a 97.4-km² area. Most streams had yields of about 140 t/km².

These sediment determinations were based on synthesized daily sediment records developed by correlating data from miscellaneous sampling with daily data from nearby sediment stations in the Alsea River basin. The determinations should be reliable because of the excellent correlations obtained.

Sediment yield in the Lake Tahoe basin, California

The relative magnitude of sediment contributed to Lake Tahoe from State highway cuts was demonstrated in a study by C. G. Kroll (1974). During water years 1972–74, less than 100 t/yr of sediment finer than 62 μm was contributed by State highway cuts. An unknown portion of the estimated 100 t/yr was contributed to the highway surface as mud falling from passing vehicles. The estimated long-term annual sediment discharge into the lake from 6 streams is 6,440 t, of which 2,090 t is finer than 62 μm. During the period 1972–74, 65 percent of the water and sediment discharge occurred during snowmelt runoff. In most streams, almost all sediment is transported in suspension.

Sediment transport from highway construction sites

Suspended sediment transported by several small streams was measured to determine the effectiveness of sediment-control measures in reducing sediment transport from highway-construction sites. J. F. Truhlar, Jr., and L. A. Reed (W. G. Weber and L. A. Reed, 1975) found that the sediment transported

from a construction site was predominantly clay; clay made up about 65 percent of the sediment transported even though the construction soils were only 20-percent clay. The large amounts of clay restrict the effectiveness of sediment-control techniques, such as rock dams and sediment traps. The study is being done in cooperation with the Pennsylvania State Conservation Commission and the State Department of Transportation.

Sediment-transport characteristics of North Carolina streams

The sediment-transport characteristics of streams were determined in a 15,540-km^2 area of the Coastal Plain and Piedmont regions of eastern North Carolina during the period 1969–73. The study by C. E. Simmons (1975) covered all or parts of 21 counties and included data for 28 sediment-sampling stations. Annual suspended-sediment yields ranged from 4.4 to 115 t/km^2. There is a decrease in suspended-sediment yield in an eastward direction from the Piedmont to the Coastal Plain.

Sediment characteristics are directly affected by topography, storm runoff, geology, land use, and manmade detention structures. At one sampling station during the 1973 water year, 44 percent of the annual suspended-sediment load was transported during 34 d of high flow. In the Piedmont region, sediment yields vary indirectly with the percentage of forest cover in the basin, but no definite relationship is apparent between forest cover and yield in the Coastal Plain. Most suspended sediment transported during floods in Piedmont streams ranges in size from sands to silts, whereas the suspended material in flooding streams in the Coastal Plain generally is clay size.

Sediment yields in Colorado oil-shale region

Sediment yields were estimated by D. G. Frickel, L. M. Shown, and P. C. Patton (1975) for 32 typical subbasins in the oil-shale region of Colorado, using a qualitative rating system involving climatic, geologic, basin, and channel characteristics. The estimates ranged from 48 to 333 m^3/km^2 for basins with areas from 0.8 to 1,629 km^2 under present, unmined conditions. Erosion transects on 26 hillslopes and 11 channels showed little change during 1 yr of observation.

Erosion from coal-mining spoils in Wyoming

During the summer of 1974, G. C. Lusby applied simulated rainstorms of 38 mm in 45 min to small basins in two coal surface-mining areas in Wyoming. Runoff and sediment yield resulting from these storms were measured on reclaimed spoil piles and from nearby undisturbed areas. The test areas averaged about 232 m^2 and were on slopes of about 18 percent. Two tests were made at each site; the first was made during prevailing antecedent moisture conditions and the second was made after the site had dried somewhat from the first test.

A good stand of introduced grasses was present on the spoils at area 1. Density of vegetation was about 17 percent greater than on the nearby undisturbed area. Despite the greater amount of vegetation present, runoff was about 12 percent greater and sediment yield was about 3 times greater from the reclaimed area than from the undisturbed area. At area 2, runoff was about 9 times greater and sediment yield was 90 times greater from the reclaimed area than from the undisturbed area. These large differences apparently resulted from the replacement of surface soils with soils containing more clay. Soils on the reclaimed areas contained about 20 percent more clay than the natural soil.

Determining sediment discharges from continuous turbidity records

J. F. Truhlar and W. P. Schaffstall reported that turbidity data were useful in computing suspended-sediment discharge in streams affected by highway construction. Data collected at several sites downstream from areas of active construction in Pennsylvania showed good correlation for individual streams between discharge-weighted daily mean turbidity and discharge-weighted daily mean suspended-sediment concentration. When suspended-sediment data were insufficient for computing suspended-sediment discharge, the discharge-weighted daily mean turbidity was computed from continuous turbidity records and water-discharge data. The discharge-weighted daily mean suspended-sediment concentration was then determined from the correlation curve and used to compute the suspended-sediment discharge. This method is a significant improvement over estimating the suspended-sediment discharge from a sediment-transport curve for streams affected by construction, and it may also yield better results for streams not affected by construction.

Effects of off-road vehicles on sediment yield

Information obtained during the 4-yr study of an area in western Fresno County, Calif., by C. T. Snyder showed that areas used for hill climbing by off-road vehicles produced larger amounts of runoff and sediment and seemed to develop pipes or solution channels more readily than an area not so used

(R. F. Miller and C. T. Snyder, 1973). The underground channels enlarge during storms, thus contributing to increased sediment yield. It had been speculated that rodent holes might be the focal point for the piping, but this argument was not supported by any increase in the number of pipes in the unused area. The vegetative cover, originally damaged by motorcycles and later damaged by a series of unusually dry years, was not improved greatly by precipitation during the 1974–75 winter.

SEDIMENT TRANSPORT AND DEPOSITION

Unstable sediments on the Mississippi Delta

In cooperation with investigators from the Coastal Studies Institute of Louisiana State University, a series of four borings were made into the submerged portion of the Mississippi Delta by L. E. Garrison and J. S. Booth in order to gain a better understanding of the mechanisms responsible for sediment instabilities. The sites, which lay in depths of water ranging from 25 to 100 m, were drilled to depths of 30 to 60 m below the mudline. The locations chosen represented a variety of bottom conditions, ranging from areas with a known history of failure to areas where the shallow acoustic stratigraphy indicated stability throughout Holocene time.

Geochemical analyses of the pore waters in recovered samples showed the presence of methane in amounts as high as 1.7 ml/l. These methane amounts bore an inverse relationship to dissolved sulfate, lending support to geochemical model results of methane generation by sulfate-reducing bacteria. Furthermore, a fairly good correlation of high methane with low shear strength indicates that methane was present in a gaseous state and played an important role in the loss of sediment strength. The area selected for its stable history contained a 25-m-thick zone high in methane content and low in shear strength, suggesting that gas generation in delta sediments spreads radially from centers of deposition and mobilizes deposits which have previously been stable. Rates at which this process proceeds have not yet been established.

CHANNEL SCOUR

Fluvial morphology at bridge crossings

W. J. Randolph and T. L. Kelly reported that an investigation of 19 western Tennessee bridge scour sites, including four sites where bridge failure occurred, indicates that scour problems at bridge crossings are often caused by manmade changes in the channel or flood plain after construction of the bridge. Channel enlarging and straightening resulted in lowering and widening the channel, channel degradation (or sometimes aggradation) owing to change in hydraulic slope, and increased scour at bridges owing to increased velocities.

Flood-plain modifications at some sites resulted in less efficient flow conveyance and higher stages. Examples of flood-plain modifications ranged from channel encroachments and fill material pushed under overflow spans to the complete blockage of two overflow bridges by a downstream levee.

AERIAL PHOTOGRAPHY

Sources of erosion in the Broad River basin, South Carolina

In order to locate sources of erosion in an area within the Broad River basin and to determine the feasibility of correlating film density with suspended-sediment concentration, S. J. Playton studied aerial photographs and suspended-sediment samples for two flow regimes. Playton determined that no significant quantities of sediment are gained or lost to the system except in Parr Shoals Reservoir. In Parr Shoals Reservoir, it appeared that during low- to average-flow conditions, suspended sediment was deposited, and during higher streamflows the deposited material was resuspended and transported downstream. Little success was realized in the attempt to correlate film density with suspended-sediment concentration during low streamflow, and the quality of aerial photographs collected during higher streamflow was not good enough to allow correlation.

GLACIOLOGY

Research in glaciology—the study of seasonal snowcover, ice, glaciers, and ground ice—by USGS scientists is directed mainly toward a better understanding of snow and ice as a water resource. Snowmelt produces much of the Nation's streamflow; glacier ice contains vast amounts of water in storage, self-regulates the release of this water, and may provide sensitive indications of climate change; river and ground ice may make difficult the development of water resources and transportation corridors in Alaska and other northern states.

Tidal glacier studies

Columbia Glacier, the largest tidal glacier in Prince William Sound, Alaska, has maintained a calving front at about the same location for the last

several centuries, whereas other tidal glaciers have catastrophically retreated. Austin Post postulated that Columbia Glacier presently ends on a shoal enclosing a deep, glacier-filled fiord and that a small retreat of the terminus could result in a catastrophic breakup of as much as 30 km of the glacier in a period of about 50 yr. Post, M. F. Meier, and L. R. Mayo, using the University of Alaska's research vessel, *Acona*, and its radio-controlled boat, *Firefish*, made a hydrographic survey of the water depth at the front of Columbia Glacier. Shoals from 2 to about 30 m deep were found along the glacier's terminus, confirming Post's hypothesis.

Glacier hydrology

A pilot study by S. M. Hodge (1975) during 1973 and 1974 on South Cascade Glacier, Wash., demonstrated that borehole-drilling techniques can be used to assess a subglacial water system. The water level in the boreholes probably represents a direct measurement of the basal water pressure. Indications are that a single borehole is representative over a domain at least 10 m in extent. Pronounced fluctuations in borehole water levels (up to 40 m) occur typically over periods of several days and seem to follow by about 2 d periods of increased water input at the glacier surface. The long-term trend in water levels supports the idea of seasonal storage and release of liquid water in glaciers.

Numerical methods in glaciology

L. A. Rasmussen (1974a) described a digital-computer program that provides bihourly direct-beam solar-radiation values and daily totals for one or more sites anywhere on the Earth, for one or more days of the year, for eight different atmospheric transmissivity values. A site may have arbitrary elevation above sea level and arbitrary topographic horizon, and the plane of the site may have arbitrary inclination from the horizontal (including vertical). The program gives the true solar times of sunrise and sunset as well as of the beginning and conclusion of other topographical obstructions of the Sun. Mathematical relationships are used to determine the instantaneous position of the Sun, its angle of incidence on the plane of the site, and the depletion of radiation due to atmospheric absorption and scattering. Simple algebraic expressions are used that closely approximate published empirical data for atmospheric refraction and for the length of the atmospheric path traversed by the Sun's rays. The annual variation of solar declination and intensity is accepted by the program as input data. This provides the user the option of supplying the data for any particular year. Care has been taken in the FORTRAN coding to enhance the ease of installation of the program on the widest possible selection of computers, both existing and anticipated, of the preparation of input data and the use of the output data, and of possible modification of the program to serve specialized purposes. The results are useful in modeling snowmelt and in many other applications.

The computer programming of the generalized three-dimensional, time-dependent flow model for temperate glaciers described by L. A. Rasmussen and W. J. Campbell (1973) was documented by Rasmussen (1974b). The term "generalized" is used because the dynamic behavior of a glacier is specified by means of the following four flow parameters: (1) the type of flow law to be used; (2) the exponent in the power-law relationship in the selected flow law; (3) the ice-to-ice viscosity coefficient for a Newtonian viscous fluid; and (4) the ice-to-bed friction coefficient. After the four parameters have been determined, the glacier is completely defined by specifying only the topography of the surface underlying it and the mass balance distribution. To aid in shortening computation time, an initial thickness distribution is estimated. Calculation of the flow of the glacier can then be carried out for a period of arbitrary length. The model was developed for the purpose of deducing the optimum values of the four flow parameters by applying it to existing glaciers. Care has again been taken in the FORTRAN coding to enhance the ease of installation of the program on the widest selection of computers, both existing and anticipated, of the preparation of the input data and the use of the output data, and of possible modification of the program.

PALEONTOLOGY

Research by USGS paleontologists involves biostratigraphic, paleoecologic, taxonomic, and phylogenetic studies in a wide variety of plant and animal groups. The results of this research are applied to specific geologic problems related to the USGS program of geologic mapping and resource investigation and to providing a biostratigraphic framework for synthesis of the geologic history of North America and the surrounding oceans. Some of the significant results of paleontological research obtained during the past year, many of them as yet unpublished, are summarized in this section by major geologic age and area. Many additional paleontologic studies are car-

ried out by USGS paleontologists in cooperation with USGS colleagues. The results of these investigations are ordinarily reported in "Regional Geological Investigations."

PALEOZOIC OF THE UNITED STATES

Redeposited trilobites in the Upper Cambrian of Nevada

The lower part of the Hales Limestone of the Hot Creek Range in central Nevada contains Late Cambrian trilobites, according to M. E. Taylor. Two types of trilobite assemblages are recognized on the basis of sedimentological characteristics: (1) Basinal assemblages that are characterized by numerous complete exoskeletons, poor size sorting, and association with thinly bedded dark-gray pyritic lime mudstones and shaley partings between lime mudstone beds and (2) allochthonous assemblages that consist of broken and abraded fossil debris that occurs in lighter colored lime grainstones and in the matrix of some limestone breccias. The basinal assemblages are thought to contain trilobites that lived in deeper water basinal habitats, whereas allochthonous assemblages represent redeposited exuviae of trilobites that lived in the upper slope or the shoal-water habitats of a carbonate platform located in eastern Nevada and western Utah.

Basinal assemblages contain trilobites that are widespread in southeastern and northwestern China. Allochthonous assemblages mostly contain elements of the so-called "*Hungaia magnifica* fauna," which was restricted to North American outer platform and platform margin sites during the Late Cambrian.

The interbedding of trilobites with widely different paleobiogeographic affinities provides a basis for more refined correlations between the Upper Cambrian rocks of the Western United States and central Asia.

Depositional environments of Ordovician fossiliferous volcaniclastic rocks

Differences in water depth and distance from shore around Early Ordovician volcanic islands are inferred from contrasting fossiliferous volcaniclastic rocks interbedded with lavas found at four places on New World Island, Newfoundland, by R. B. Neuman (USGS) and G. S. Horne (Wesleyan Univ.). At one place, poorly sorted, obscurely bedded conglomeratic sandstone consisting of red volcanic debris containing abundant gastropods and cephalopods as well as abraded and broken brachiopods indicates nearshore accumulation in shallow, turbulent water. Waterlaid tuffs at three places show different amounts of reworking that, together with differences in (1) the abundance of calcareous algae, (2) the composition of invertebrate fossil assemblages (largely brachiopods), and (3) the nature of fossil preservation (incidence of shell articulation, evidence of shell borings), indicate deposition in progressively deeper water. These interpretations should be useful in identifying centers of volcanic activity in similar rocks in Maine and elsewhere in the northern Appalachians.

Early Devonian ostracodes from Nevada

A rich assemblage of silicified ostracodes has been picked from residues from the *Eurekaspirifer pinyonensis* zone of the McColley Canyon Formation (Emsian) provided by J. G. Johnson (Oregon State Univ.). J. M. Berdan (USGS) reported the presence of more than 35 taxa, of which 3 genera and many of the species are new. The assemblage is a mixture of Appalachian forms and forms with Eurasian affinities and includes one species that hitherto has been found only in the Early Devonian part of the McCann Hill Chert in Alaska.

Septal carinae in Devonian corals

Study of the microstructure of carinae in Middle Devonian *Heliophyllum* (rugose coral) from New York by W. A. Oliver, Jr., and J. E. Sorauf (S.U.N.Y., Binghamton) showed that three distinct types exist. Type I (simple, monacanthine trabeculae) is the only type found in earlier *Heliophyllum* and in the early ontogenetic stages of all *Heliophyllum*. Types II (compound trabeculae, branching prolifically) and III (compound, branches few and parallel) appear higher in the section but only in the mature stages of individuals.

In the higher part of the section (Tioughnioga Stage), all samples studied have one dominant carina type that appears in over 75 percent of the individuals studied from that sample, but different types predominate in different stratigraphic (that is, lithologic) units. Thus a selection pressure favoring the type best adapted to the local environment is suggested. Colonial *Heliophyllum* have been studied only in collections from the Deep Run Member of Cooper (1930) of the Ludlowville Formation; predominant types are as follows: branching colonies, type I; massive colonies, type III; and solitary *Heliophyllum* from the same unit, type II. Further study of colonies may help determine whether this apparent linkage of growth form and carina type is constant or also varies with stratigraphic unit.

Late Ordovician Bryozoa in Western United States

Collections of Ordovician bryozoans from Nevada and Wyoming submitted to O. L. Karklins for identification by T. B. Nolan and R. J. Ross, Jr., extended the geographic range of the trepostomes *Calloporella, Batostoma manitobense* Ulrich, *Rhombotrypa* cf. *R. multitabulata* Utgaard and Perry, and cryptostomes *Goniotrypa, Pachydictya hexagonalis* Ulrich, and *Sceptropora. Calloporella, Batostoma* cf. *B. manitobense, Goniotrypa,* and *Sceptropora* are found in a yet unnamed lithic unit, probably of Late Ordovician age, in Beacon Peak quadrangle in Nevada. Of these bryozoans, *Goniotrypa* and *Sceptropora* occur in the Stony Mountain Formation in Manitoba, Canada, and in the Eastern United States, but *Calloporella* occurs only in the eastern regions. In Kentucky, *Calloporella* appears to be restricted to the Garrard Siltstone (Weir and Greene, 1965) in south-central Kentucky. *Batostoma manitobense,* however, occurs in the upper member of the Bighorn Dolomite in the Hidden Tepee Creek quadrangle and in the Stony Mountain Formation but has not been reported from the eastern regions.

Rhombotrypa cf. *R. multitabulata* and *Pachydictya hexagonalis* occur in the upper member of the Bighorn Dolomite and in the Stony Mountain Formation. Of these bryozoans, only *Rhombotrypa multitabulata* is found in the Whitewater Formation of Indiana and Ohio (Utgaard and Perry, 1964).

North American Mississippian coral zoogeography

A study by W. J. Sando, E. W. Bamber, and A. K. Armstrong of the distribution of coralliferous facies and the degrees of endemism and generic similarity of Mississippian coral faunas permitted recognition of five zoogeographic provinces and five zoogeographic subprovinces in North America. Analysis of indices of endemism and similarity suggests the following major conclusions: (1) Zoogeographic regions on the periphery of the North American continent had favorable connections for migration to other coralliferous areas of the world, which permitted maximum gene flow; (2) zoogeographic regions in the interior of the North American continent were relatively isolated genetically and were characterized by coral faunas with low to high endemism throughout Mississippian time; (3) gene flow was highest along continuous shallow-water carbonate shelves and was impeded by areas of terrigenous sedimentation and areas of deeper water; and (4) similarities between faunas of different zoogeographic regions generally tend to vary inversely with the migration route distance between these regions, but other factors that affected gene flow modified the distribution patterns significantly.

Biostratigraphy of the Mississippian Leadville Limestone, San Juan Mountains, Colorado

In the San Juan Mountains, the Leadville Limestone disconformably overlies the Ouray Limestone, which is of Devonian (Famennian) age. Generally, the Leadville Limestone can be divided into two parts. The lower part, 2 to 50 m thick, consists of an unfossiliferous dolomite and lime mudstone that were deposited in subtidal to supratidal environments. Their age is uncertain. Overlying these are 2 to 26 m of pelletoid-echinoderm-ooid-foraminiferal packstones-wackestones that contain a microfossil assemblage of zone 9, which is of Keokuk age (Osagean, late Tournaisian). These fossiliferous limestones were deposited in open, shallow marine waters.

A regional unconformity and a pre-Pennsylvanian erosion surface at the top of the Leadville Limestone represent a stratigraphic hiatus encompassing Meramecian, Chesterian, and probably parts of early Morrowan time. The lowermost beds of the overlying Pennsylvanian Molas Formation formed as a residuum composed of nonmarine mudstone, solution-rounded limestones, and cherts on top of the Leadville Limestone.

A major marine transgression occurred in zone 9 (late Osagean) time in northern Arizona, southern Colorado, New Mexico, and southern Utah. The crinoidal-foraminiferal limestones of the Leadville Limestone of the San Juan Mountains are part of a once-extensive carbonate sheet. Time-stratigraphic equivalents, open marine carbonate rocks, are the Mooney Falls Member of the Redwall Limestone of the Grand Canyon in Arizona to the west and the Kelly Limestone of west-central New Mexico to the south. The Espiritu Santo Formation, to the southeast in north-central New Mexico, is a subtidal-supratidal facies of the zone 9 beds of the Leadville Limestone.

Upper Devonian conodont biofacies in Western United States

Conodont faunas of the upper Famennian *Polygnathus styriacus zone* were recognized by C. A. Sandberg in a large region of the Western United States extending from northern Montana southward to southern New Mexico and from central Nevada eastward to central Wyoming. The faunas were deposited in environments ranging from bathyal to nearshore marine. The eugeosynclinal and miogeo-

synclinal biofacies are well diversified and contain many species that are readily correlatable with species of the standard Upper Devonian conodont zonation in Germany. The faunas of the cratonic platform, however, contain few deep-water species and become progressively more specialized shoreward. Highly specialized nearshore cratonic biofacies contain poorly known bizarre species that would be difficult to assign zonally were it not for their minor mixing with better known deep-water species in some outer cratonic platform biofacies. Recognition of the great diversity of conodont biofacies in a single conodont zone permits paleoecologic interpretations that will aid in analyzing depositional environments of petroleum source beds and also makes possible age determinations of many previously undatable conodont collections from the cratonic interior.

Invertebrate assemblages from the Kanawha Formation, West Virginia

Sections described for the proposed Pennsylvanian System stratotype in West Virginia have yielded brachiopod faunas in several beds of Middle Pennsylvanian age. Preliminary evaluation of brachiopods collected and identified by T. W. Henry from the Eagle limestone of White (1891) indicated a correlation with the upper Morrowan *Linoproductus nodosus* zone of the midcontinent region. This occurrence suggests that the top of the Morrowan Series is actually within rather than at the base of the Middle Pennsylvanian Series, as early correlations had indicated.

Evidence of Vojnovskyales in north-central Texas

The identification of the Vojnovskyales, typified by *Vojnovskya paradoxa* Neuburg 1955, is based on gymnospermous fragments from the Lower Permian of Siberia. These plants are characterized by fan-shaped leaves and bisexual fructifications containing winged seeds and long, narrow polleniferous organs; relationships of the plants within the gymnosperms are completely enigmatic.

A large suite of Permian plants from Texas and Kansas, collected by S. H. Mamay, contained many fan-shaped leaves, detached winged seeds, and one partial cone with attached leaves and structures resembling pollen organs; together, these organs closely resemble those of Neuburg's *Vojnovskya*. The American fossils are much like the Vojnovskyales and appear to represent a close link between the American and Siberian floras, both morphologically and chronologically.

Palynological analyses

Thirteen samples of the Laurel coal and associated roof and seat rock collected from the Isonville quadrangle in eastern Kentucky were prepared and examined for spore-pollen content by R. M. Kosanke. The most abundant genus is *Laevigatosporites; L. globosus* is the most abundant species, followed by *L. minutus* and *L. ovalis*. A single specimen of *Zosterosporites triangularis* was identified from the seat-rock sample. This taxon previously had been reported from the Princess No. 5 through the Princess No. 5B coal. Two samples of the Laurel coal contained several specimens provisionally assigned to *Schopfites*, which previously had been identified from the Princess No. 6 and No. 7 coals of northeastern Kentucky. The evidence suggests that the Laurel coal does not correlate with either the Princess No. 5B or the Princess No. 6 coal but rather occurs between these two coals. The occurrence of a coal between the Vanport Limestone Member of the Breathitt Formation and the Princess No. 6 coal is not unique. The Lawrence coal of Lawrence County, Ohio, occurs at approximately this position.

MESOZOIC OF THE UNITED STATES

Ammonoid fauna in Nacatoch Sand

A varied ammonoid fauna of very Late Cretaceous age (Maestrichtian) was discovered in the Nacatoch Sand in Hempstead County in southwestern Arkansas by B. F. Clardy and W. V. Bush (Arkansas Geological Commission). Collections made in 1973 and 1974 by Clardy with W. A. Cobban and R. E. Burkholder (USGS) include *Nostoceras alternatum* (Tuomey) and *Solenoceras nitidum* Cobban, species previously known only from the Ripley Formation of Mississippi, Alabama, and Georgia. Other ammonoids in the collections from the Nacatoch Sand consist of representatives of the genera *Anagaudryceras?*, *Pseudophyllites*, *Baculites*, *Discoscaphites*, and *Sphenodiscus*.

Fossil gymnosperm seeds from the Morrison Formation

Although remains attributed to the araucarian conifers are common in Mesozoic rocks of the United States, first proof that the modern Southern Hemisphere genus *Araucaria* was present is furnished by hundreds of silicified cone scales from a locality in the Morrison Formation (Upper Jurassic) of Utah. These fossils, studied by M. E. J. Chandler and R. A. Scott, show that two sections of the extant genus are represented, one still living in Australia and

the other extinct but related to the modern section containing *Araucaria bidwelli.* About 10 other genera of pteridosperms and cycadophytes are also represented by reproductive structures at this locality. These plants are strikingly different from previously described forms and reveal a floral diversity for Morrison time not suspected from the scanty leaf fossils already known. No angiosperm fossils are present.

CENOZOIC OF THE UNITED STATES

Latitudinal floral differentiation in the Paleocene

The presence of pollen grains of *Thomsonipollis* in the Paleocene part of the Dawson Formation of Colorado is evidence for a latitudinal difference in floras during the Paleocene, according to R. H. Tschudy. Pollen of this genus is absent or extremely rare in the Paleocene of Wyoming, Montana, and North and South Dakota. This pollen, however, is common in the Upper Cretaceous and Paleocene of southern Colorado and New Mexico and in the uppermost Cretaceous, Paleocene, and lower Eocene of the Mississippi embayment region. The northern limit of the *Thomsonipollis* floral province was probably about the latitude of Denver, Colo.

Pollen floras of the Pliocene-Pleistocene transition, west Snake River Plain, Idaho

Rocks of the Idaho Group of the western Snake River Plain contain a variety of plant fossils, including fossil wood, fruits, leaves, and pollen. The combined evidence gathered by earlier workers, including evidence from a recent pollen study by E. B. Leopold, revealed the following vegetation sequence for the old flood plain of the Snake River, near Glenns Ferry, Idaho:

1. Hemphillian (Poison Creek Formation, Banbury Basalt, and Chalk Hills Formation): mixed conifer and hardwood forest and woodland. Hardwood genera such as *Carya, Ulmus, Fraxinus, Alnus, Abies,* and *Salicaceae* grew at least near the river. Conifers were largely *Pinus.*
2. Early Blancan (Glenns Ferry Formation): *Pinus-Juniperus* savanna and woodland. Grasses predominated as understory. Climate presumed to be moister than it is now.
3. Late Blancan and Irvingtonian (Bruneau Formation of middle Pleistocene age): *Artemisia* steppe, very open and treeless, as it is now. Climate was probably as dry as it is now. Some horizons (younger, undated) suggest an advance of *Picea* on the Snake River Plain.

The major phases of contrasting vegetation are of interest in considering the environmental setting in which the rich local faunas of these periods occurred. Since the modern vegetation of the area is sage steppe, the late Tertiary fossils indicate a climate considerably more moist than that of today, lasting at least until the beginning of the Pleistocene. In effect, the lower ledge of tree line has moved upslope some 600 to 900 m since the Pleistocene.

Pliocene diatoms from the Teewinot Formation, Wyoming

A sequence of samples collected by J. D. Love and G. W. Andrews from the Teewinot Formation at the Boyle Ditch locality in the Jackson Hole National Elk Refuge contained 75 taxa of nonmarine diatoms. The frequent occurrence of at least seven extinct nonmarine diatom taxa suggests an age not younger than late Pliocene. The diatom assemblages contain many benthic taxa, which suggest deposition in a shallow lacustrine environment. Increases in the abundance of the planktonic species *Melosira italica* and *M. granulata* suggest occasional deepening of the waters. The assemblages are predominantly freshwater in character, but some contain components of saline, salt-indifferent, and salt-tolerant freshwater taxa. These suggest that seasonal fluctuations in alkalinity and salinity occurred during deposition. However, the common element running through the sequence of assemblages indicates that no profound environmental change occurred during the deposition of these Teewinot sediments.

Delmontian diatoms and silicoflagellates

J. A. Barron investigated the diatom and silicoflagellate biostratigraphy of the type Delmontian Stage (upper Miocene) near Monterey, Calif. Early late Miocene diatoms and silicoflagellates characteristic of the lower Mohnian Stage at Newport Bay, Calif., are present in the type Delmontian strata. These results support the benthonic foraminiferal studies of R. L. Pierce and suggest that the Delmontian is coeval, at least in part, with the Mohnian.

The type section of the *Bolivina obliqua* Zone conformably overlies the Mohnian stratotype near Los Angeles, Calif., and contains early Pliocene diatoms and silicoflagellates. This configuration suggests that the Mohnian Stage extends into the Pliocene.

Miocene biostratigraphy, western Washington

New molluscan data from the Clallam Formation, an 800-m-thick sandstone exposed along the northern margin of the Olympic Peninsula, Wash., indicated reassignment from the middle Miocene to the lower Miocene, according to W. O. Addicott. Inner sublittoral assemblages of the Clallam mark the concluding phase of a late Eocene to early Miocene depositional cycle in northwestern Washington. They also represent a previously unrecognized time-stratigraphic unit of at least zonal, if not stage, magnitude. This unnamed unit is coeval with the upper part of the "Vaqueros Stage" of California. It is referable to the later part of the provincial lower Miocene.

Miocene and Pliocene Cetacea from the Lee Creek phosphate mine, North Carolina

The open-pit phosphate mine of Texasgulf, Inc., at Aurora in Beaufort County, N.C., is the richest known source of fossil marine mammals in the world. The fossils come from the Pungo River Formation of middle Miocene age and the Yorktown Formation of early and late Pliocene age. As they are dug up by a 56-m^3 dragline, the bones are mostly fragmentary, but one partial baleen whale skull, several porpoise skulls, and one pygmy sperm whale skull were preserved in calcareous concretions. Despite the fragmentary nature of the material, F. C. Whitmore, Jr. (USGS), and J. A. Kaltenbach (George Washington Univ.) identified 11 genera of Cetacea from the Pungo River Formation and 10 from the Yorktown Formation.

The Pungo River fauna shows closest affinity to the fauna of the Calvert Formation of Maryland. Particularly common, as in the Calvert, are remains of the long-beaked porpoises *Rhabdosteus* and *Furhinodelphia,* the latter also being well known from the Miocene of Belgium. At least three species of Squalodontidae are present: *Phocageneus* cf. *P. yenustus* Leidy, *Squalodon* cf. *S. tiedemani* Allen (similar to, but not conspecific with, *S. dalpiazi* Fabiani of the middle Miocene of Italy), and *S. calvertensis* (probably conspecific with forms from the Bolderian (middle Miocene) of Belgium). Other porpoise genera also found in the Calvert are *Kentriodon, Delphinodon,* and *Lophocetus.* A few tiny ear bones resemble those of the porpoise *Nannolithax* from the Temblor Formation (lower and middle Miocene part) of California. Cetotheres (primitive whalebone whales) are present but cannot be identified as to genus.

Whereas the Pungo River fauna consists of extinct genera, the Yorktown Formation, which includes representatives of living genera, has a decidely modern aspect. More specimens are recovered from the Yorktown, and it is possible to make a rough estimate of the dominant members of its fauna. On the basis of the number of earbones found, the dominant Cetacea are dolphins (Delphinidae), pygmy sperm whales (Kogiinae), and belugas (Delphinapterinae). The abundance of the latter two is surprising: the pygmy sperm whale, although known to have worldwide distribution, is rare today, and the beluga, a small white whale that inhabits estuaries, is a cold-water animal and rarely ventures south of the Gulf of Saint Lawrence. Neither of these subfamilies is represented in the extensive collections of Pliocene Cetacea from Belgium in the Museum National d'Histoire Naturelle in Brussels. Many teeth of large sperm whales are found in the Yorktown; some are indistinguishable from teeth of the modern genus *Physeter.* The modern beaked-whale genera *Mesoplodon* and *Ziphius* are present, although rare. Among the baleen whales, Balaenopteridae (finbacks) and Balaenidae (right whales) are common.

OTHER PALEONTOLOGIC STUDIES

New information on early Paleozoic bivalves

Significant new information and discoveries about the functional morphology, systematics, biological placement, biostratigraphy, and phylogeny of early Paleozoic bivalves were obtained by John Pojeta, Jr. (USGS), in conjunction with Bruce Runnegar (Univ. of New England, Armidale, Australia) and J. H. Shergold and Joyce Gilbert-Tomlinson (Australian Bureau of Mineral Resources). They dealt with the long poorly understood fossils known as the Ribeirioida, Conocardioida, and *Fordilla troyensis.*

Pojeta and Runnegar were able to show that *F. troyensis* is the oldest known pelecypod mollusk and that it is the only member of its class presently known from the Cambrian. They also noted that, in the earliest Cambrian, mollusks had already diversified into three classes: Monoplacophora, Gastropoda, and Rostroconchia; subsequently, in the late Early Cambrian, rostroconchs gave rise to the Pelecypoda. Previously, it had been thought that these classes of mollusks arose later in the Cambrian or in the Early Ordovician.

Pojeta and Runnegar have shown that the ribeirioids and conocardioids form a new class of mollusks

called the Rostroconchia, which are neither bivalved arthropods nor pelecypods. They have provided a new biostratigraphic tool—a group of organisms heretofore neglected because they were not recognized as a biological entity—and have monographed all known Cambrian and Ordovician species from North America, western and central Europe, Siberia, north Africa, and Manchuria. Pojeta, Gilbert-Tomlinson, and Shergold have monographed all known Cambrian and Ordovician rostroconchs from Australia and have established a rostroconch biostratigraphy for the Upper Cambrian and Lower Ordovician.

Canadian Arctic Albian (Cretaceous) foraminifers

Samples from the Christopher Formation on the Amund Ringnes Island of the Canadian Arctic Archipelago have yielded an Albian foraminiferal assemblage consisting of 30 species. These faunas represent an important biogeographic link between Albian species recognized in Alaska and those recognized in European localities, especially England and northwestern Germany. The faunas are indicative of a middle Albian age and are unusual by Arctic standards in the number of calcareous species represented. The species comprise a neritic assemblage from a section whose environment of deposition passed from a transgressive to a regressive phase, according to W. V. Sliter. Recognition of the successive bathymetric assemblages of these Albian foraminifers provides important data for the paleoecologic interpretation of Alaskan and Californian species of similar age.

Metazoan imprints from 620-m.y.-old rocks in North Carolina

Large U- and J-shaped imprints of soft-bodied Metazoa are abundant on a small bedding-surface exposure about 16 km north of Durham, N.C., in the Carolina slate belt. They show a strong preferred orientation, with the long axes trending N. 55° E. to S. 55° W. It is believed that this orientation and perhaps the U and J shapes were produced by currents that carried the flaccid tubular structures downslope from the coast of an adjacent volcanic land area. Available radiometric dating implies an age near 620 m.y. The most common type of U- and J-shaped imprint is described as a new genus; it is a sedentary, deposit- or filter-feeding polychaete annelid. Other taxa may be present, including possibly a turbellarian flatworm. These imprints constitute the first record in the United States of the global burst of soft-bodied metazoan diversification that ushered in the Paleozoic Era and Phanerozoic eon. Since its marine volcanogenic sediments are both fossiliferous and capable of being radiometrically dated at many points, the slate belt is a promising region for delineating the base of the Paleozoic and Phanerozoic and the relations between Ediacarian and Cambrian. P. E. Cloud, Jr. (USGS), is preparing a report on these objects in collaboration with James Wright (Univ. of California, Santa Barbara) and Lynn Glover III (Virginia Polytechnical Institute).

GROUND-WATER HYDROLOGY

USGS ground-water hydrology research continues to cover a broad range of subjects with the common objectives of (1) better understanding ground-water systems and (2) developing and applying new technical methods of study to improve management of ground water as an important national resource.

Artificial-recharge studies ranged from geological and geochemical aspects of artificial recharge to quantitative tests of percolation basins.

Research on the hydrology of carbonate-rock terranes included aquifer testing to determine the water-bearing properties and the movement of contaminants through fractures.

Model simulation of aquifer systems, oriented toward studying both flow and quality changes in ground water, received much attention during the year. Mathematical contributions included the development of a finite-difference model for simulation of ground-water flow in three dimensions.

Geophysical methods, including high-resolution seismic reflection and direct-current resistivity, were used successfully in investigating stratigraphic positions and lithologic characteristics of aquifers.

Results of other studies showed that ground-water movement is influenced by the presence of subsidence fissures in fractured rocks that overlie areas of mined-out coal beds and that resultant changes in ground-water circulation in these rocks may account for some capture of flow from wells and springs, greater flooding of mines, and increased acid mine-water discharge to streams.

Artificial recharge

Alaska.—Artificial-recharge operations were conducted from May through November 1974 at a 40,500-m^2 pit near Ship Creek in the Anchorage area. G. S. Anderson and N. A. Matson, Jr., reported that the infiltration rate of 0.3 to 0.45 m/d, total recharge rate of 15,100 m^3/d, and increase in potentiometric

head of 5.5 m in the vicinity of the pit are similar to values obtained from a 2-mo test in 1973. Temperature logs from a well at the edge of the pit indicate that the 10° to 15°C Ship Creek water, which was used for recharge operations, caused a local increase in ground-water temperature. Normally, ground-water temperature in the Anchorage area is between 3° and 4°C.

Florida.—Predicted water shortages in southern Florida have led to an investigation by F. W. Meyer of the feasibility of injecting seasonal surpluses of freshwater runoff into saline artesian aquifers as a water-conservation measure. A 335-m test well is under construction at a site near the city of Miami's water-treatment plant at Hialeah to identify potential injection zones. Plans call for initial injection of ground water to determine the feasibility of recovering the injected water.

Kansas.—Ponds used for artificial-recharge tests in western Kansas gradually became plugged by sediment deposition and biological activity that reduced recharge rates. J. B. Gillespie showed that tilling of the native sod (derived from loess) in the ponds restores the recharge capacity of the ponds. In 1973, 40.5 m of water was recharged through a pond in 27 d; in 1974, after the deposited sediments were tilled, the test pond recharged 40 m of water in a similar period.

Texas.—Results of laboratory studies by D. C. Signor, W. W. Wood, and R. F. Brown showed that the condition of a sand-grain surface has a major effect on retention of inflowing clay and clogging of a porous matrix. Washed and acidized sand from the Ogallala Formation retained a coating of clay and iron oxide on the grains. Repacked columns of sand of two size ranges (74–595 μm and 120–1,680 μm) and with the same relative particle-size distribution were subjected to a clay-suspension inflow. The clay suspension was 500 mg/l of a sodium montmorillonite with an initial inflow velocity of 0.2 cm/s. After 230 min of flow, the average intrinsic hydraulic conductivity was reduced by 93 percent for the 74- to 595-μm sand size and 78 percent for the 120- to 1,680-μm sand size.

In a similar experiment, a major part of the clay coating was removed from the sand grains by mechanical stirring, but the particle-size range and distribution were changed only slightly. After 284 min of clay-suspension inflow, the intrinsic hydraulic conductivity of the fine material was reduced 60 percent, and that of the coarse material was reduced 57 percent.

Evaluation of factors affecting clogging should aid in site evaluation when feasibility of artificial recharge is to be determined.

Wisconsin.—Results of a study by R. P. Novitzki showed that recycling water to the ground-water system is an effective means of increasing the quantity of water available for use, of controlling or avoiding environmental pollution, and of controlling water temperatures. Waste water from a fish hatchery was recharged to the ground-water system through an infiltration pond for 15 mo. Subsequent calculations showed that 83 percent of the recharge water was recirculated to a nearby water-supply well. Nitrate nitrogen levels in the water supply did not exceed 4 mg/l throughout the recycling period. Mass-balance equations relate nitrate nitrogen levels to imposed loading and to the efficiency of the recycling system.

Estimates indicate that the local aquifer could support operation of a hatchery producing more than 50,000 kg of cold-water fish without significant degradation of the local water supply or the regional ground-water system.

The temperature of the water supply also could be predicted. Equations were developed that related water-supply temperature to air temperature, the size of the recycling system, and the recycling efficiency. During operation of a full-scale hatchery, utilizing continuous recycling, water-supply temperatures would range from 7° to 15°C. Water-supply temperatures could be maintained in an optimum range (10°–16°C) if recycling were practiced for 8 mo of each year.

Hydrology of carbonate-rock terranes

In a continuing evaluation of the water-bearing potential of carbonate rocks in east-central Iowa, K. D. Wahl used air-inflated packers above and below a submersible pump for testing selected zones to determine ground-water yield. The specific capacity of zones tested in one well ranged from 1.76 to 0.0021 $l\,s^{-1}\,m^{-1}$. Further refinement by borehole flow meter indicated that the zone having a specific capacity of 1.76 was fed by one major opening at a depth of 65 m. Packer tests also allowed heads to be measured in the different zones and resulted in a better understanding of ground-water movement in the area.

Carbonate rocks are a major source of ground water for municipal, commercial, and domestic users in eastern Wisconsin. Results of a study by M. G. Sherrill indicate that in areas of ground-water recharge, contaminants can enter the dolomite aquifer

through thin soil and glacial-drift cover and move with ground-water flow through a well-developed fracture system. Vertical fractures provide the avenues by which both organic and inorganic contaminants enter the aquifer.

Mathematical methods in ground-water hydrology

A finite-difference model for simulation of ground-water flow in two dimensions, originally developed by G. F. Pinder (1970), was subsequently modified by Pinder, (unpub. data, 1970), P. C. Trescott (1973), and Trescott, Pinder, and S. P. Larson (unpub. data, 1975). The most recent version is more completely documented than previous versions and includes the following options for solution of the simultaneous finite-difference equations: (1) The IADI (iterative alternating direction implicit) procedure, (2) line-successive overrelaxation, and (3) the strongly implicit procedure. Three options for numerical solution are included because the IADI procedure has not converged for all problems.

A finite-difference model for simulation of ground-water flow in three dimensions was written by Trescott (unpub. data, 1975). The model uses the strongly implicit procedure, a numerical procedure that H. G. Weinstein, H. L. Stone, and T. V. Kwan (1969) claim is less subject to roundoff error and converges faster than IADI. The model has been used to obtain a steady-state solution for ground-water flow in the Piceance Creek basin in northwestern Colorado. Twenty-one hundred nodes were used to simulate two aquifers and an intervening confining bed; the solution required 90 s of computer time on the IBM 370/155. J. B. Weeks (J. B. Weeks, G. H. Leavesley, F. A. Welder, and G. J. Saulnier, Jr., 1974) obtained a steady-state solution for this problem with a quasi-three-dimensional model developed by J. D. Bredehoeft and G. F. Pinder (1970), but that model required more computer time, and numerical difficulties were encountered.

Aquifer model studies

As part of a continuing study of the alluvial aquifer of the Ohio River valley in Kentucky, J. M. Kernodle used a two-dimensional digital flow model to simulate the aquifer's observed response to a flood on the river. Data for the model were obtained from five sites at which two 3.81-cm-diameter observation wells were augered and cased, and continuous water-level recorders were installed. The results from four of these sites were summarized by H. F. Grubb (1975).

Simulated aquifer response was matched to the observed response by adjusting the modeled hydraulic conductivity and specific yield of the aquifer, as well as the hydraulic conductivity of the riverbed and river bank. After obtaining a suitable match, the digital model was used to illustrate theoretical aquifer response to various simulated well-field designs and pumpage rates.

Results of the study showed that the technique of using the passage of a flood-generated wave through the alluvial aquifer to calibrate a digital ground-water flow model is both practical and, when compared to conventional aquifer tests, relatively inexpensive.

The USGS digital ground-water flow model (P. C. Trescott, 1973) was used by L. F. Land to determine the hydraulic characteristics of the shallow aquifer at the sites of several pumping tests in Palm Beach County, Fla. The aquifer responds as an artesian aquifer with an overlying leaky confining bed.

The artesian sandstone aquifer of southeastern Wisconsin and adjacent northeastern Illinois was modeled by H. L. Young, using 1880–1973 pumpage data. The digital-computer model covers 15,000 km^2 in Wisconsin and 18,000 km^2 in Illinois. Modeled transmissivity ranged from 0.22×10^3 to 0.29×10^3 m^2/d. Verification was obtained using vertical hydraulic conductivity ranging from 2.0×10^{-4} to 1×10^{-3} m/d in the recharge area, and from 1.2×10^{-6} to 0.8×10^{-4} m/d for the confining bed (Maquoketa Shale). Reasonable approximations of the actual drawdown from 1880–1973 and from 1961–73 were achieved. The Southeastern Wisconsin Regional Planning Commission will use the model in their planning activities.

T. J. Durbin and J. A. Skrivan designed a computer algorithm for the calibration of distributed-parameter mathematical ground-water models. The algorithm, based on the Gausse-Legendre least-squares curve-fitting method (D. J. Wilde and C. S. Beightler, 1967), has been used to estimate transmissivity and specific yield for a model of the Coachella Valley, Calif.

Water-quality modeling

S. G. Robson used a profile-oriented water-quality model to simulate hydrologic conditions in a well-documented area in southern California where water-quality degradation is associated with subsurface waste disposal. The model was used to examine data requirements, model parameter sensitivity, and advantages and disadvantages of the profile model

compared with those of an existing areal-oriented water-quality model.

The profile model may be used to simulate confined or unconfined aquifers with nonhomogeneous anisotropic hydraulic conductivity and nonhomogeneous storage coefficient, porosity, and saturated thickness. The model input parameters were more difficult to quantify for a profile model than the corresponding parameters had been for the areal-oriented model. However, the sensitivity of the profile model to the input parameters is such that moderate errors of parameter estimation allow acceptable model results. Simulation of hypothetical ground-water-management practices indicated that the profile model is applicable to problem-oriented studies and can provide quantitative results for a variety of management practices.

R. E. Fidler used a computer program to prepare contour maps for selected ground-water-quality parameters based on approximately 200 chemical analyses of water from wells drilled in the limestone and dolomite aquifers of western Ohio. This contouring program is a flexible and relatively simple method for comparing water-quality data to a regional ground-water flow system. One map shows lines of equal concentrations of dissolved solids which range from 317 mg/l to 3,120 mg/l. The areal distribution of dissolved-solids content as represented by the contours suggests that areas of high mineral concentrations are areas of ground-water discharge and areas of low mineral concentrations are areas of recharge.

A comparison between surface- and ground-water quality was made by superimposing the data from chemical analyses of stream base flow onto the ground-water-quality contour maps. The level of concentration of selected parameters for base flow is shown by a color pattern along the stream channel and can be compared to the contours depicting ground-water quality.

Geophysical methods

A high-resolution seismic-reflection investigation of offshore areas adjacent to Lee and Collier Counties, Fla., was made by T. M. Missimer and T. H. O'Donnell to determine the stratigraphic position and geometry of the upper and lower Hawthorn aquifers in the coastal areas. Seismic profiles were made to depths in excess of 500 m with good resolution by using a kilojoule sparker. The seismic profiles showed that the subsurface formations are extensively folded and that the structural fabric trends about N. 5° W. In one area, where, interaquifer leakage of saline water has occurred, the seismic record indicated the presence of high-angle fractures with little vertical displacement. It is not known whether the interaquifer leakage is the result of these fractures or if other mechanisms are involved.

Direct-current resistivity measurements were made in two small alluvial valleys in eastern Wyoming to determine alluvium characteristics and ground-water potential. Schlumberger depth soundings by W. J. Head and R. W. Knottek in the Beaver Creek valley in Weston County have resistivity values ranging from 0.7 ohm-m to 5.5 ohm-m. Unusually low values are attributed to montmorillonite clay weathering products which contain water high in dissolved salts. Small resistivity changes noted in each of the soundings suggest a similarity of the grain size, moisture content, and composition of the sediments. The water-yielding potential of this material is virtually nonexistent. Depths to the consolidated Pierre Shale of Cretaceous age range from 11 to 57 m. Results at one site were confirmed by auger test drilling.

Soundings of the alluvium in the Horse Creek valley in Goshen County have resistivity values ranging from 30 ohm-m to 74 ohm-m. Initial interpretation indicates the higher values to be associated with clay-free gravels containing freshwater. Depth of alluvium to the Brule Formation of Oligocene age ranges from 9 to 22 m. The Brule is a fairly conductive clay-rich siltstone layer that contains large quantities of freshwater in zones of secondary porosity.

Underground waste disposal

R. M. Waller reported that injection of brine into a new disposal well below a depth of 366 m near Seneca Lake in New York was started by a salt-mining company in late 1974. A network of existing wells and streams was selected to monitor the chemical composition of the overlying shallow freshwater aquifer. The monitoring program was complicated by a 37,900-m^3 spill from a brine pond a month prior to the start of injection. The spill, however, demonstrated the movement of brine from the pond area to one of the monitor wells. Previously observed variations in chloride concentration of the shallow ground water were probably caused by similar pond leakage or spills.

Ground-water movement in fractured bedrock

Ground-water circulation in shallow bedrock units consisting of sandstone, limestone, shale, claystone,

coalbeds, and underclays of the Conemaugh and Monongahela Groups of Pennsylvanian age in Allegheny County, Pa., is controlled chiefly by joint and fracture systems and to some extent by bedding planes. Joint and fracture systems of these bedrock units commonly have limited hydraulic connection, and although the relative rates of ground-water movement in these units have not been determined, the units are generally considered to have low hydraulic conductivity. According to Seymour Subitzky, in areas where these units are underlain by mined-out parts of the Upper Freeport and Pittsburgh coalbeds, subsidence fissures resulting from mine-roof collapse transect the joint and fracture systems of the overlying bedrock units. Although soil particles commonly fill the upper segments of these fissures, it is believed that they remain open at depth. Where hydraulic connection between these fissures and the joint and fracture systems occurs, ground-water circulation in the bedrock increases. Locally, the greater hydraulic connection in these units has captured flow that supported some wells and springs. Where hydraulic connection of fissures with joint and fracture systems occurs in bedrock units overlying mined-out areas in the county, ground-water inflow to mines tends to be enhanced and contributes to mine flooding. Where mine flooding occurs and remains unabated in above-drainage and unsealed mines, acid mine-water discharge to streams is increased.

New tritium data reduce estimates of ground-water velocity

From 1966 through 1970, USGS scientists sampled and tested tritium concentrations of well waters collected along two traverses extending from the west side of the San Joaquin Valley, Calif., across the valley trough into the recharge area. J. F. Poland and G. L. Stewart (1975) summarized the findings and concluded that ground-water velocities are less than one-eighth as rapid as those reported by others in an earlier paper based on 1963 sampling for thermonuclear tritium analysis.

SURFACE-WATER HYDROLOGY

The objectives of research in surface-water hydrology are to define the magnitude and variation of streamflow in time and space, both under natural and manmade conditions, to understand the flow process in stream channels and estuaries, and to define the rates of movement and dissipation of pollutants in streams.

Hydraulic and hydrologic modeling

V. R. Schneider used a theoretical potential-flow model to estimate more accurately the length along which losses are computed in approach sections to highway encroachments. The contracted-opening method yielded more accurate estimates of discharge and of backwater when a more accurate estimate of length was used. An improved method of estimating energy loss in the expansion reach also was devised.

M. E. Jennings reported the development of computer models of surface-water systems. Those for stream-quantity analyses include streamflow and reservoir-routing programs, stream-aquifer interrelationships, reservoir-systems analyses, sediment-transport computations, and data-management routines. Computer models for stream quality include unsteady-state DO analyses for streams, steady-state estuarine DO analyses, and BOD analyses.

A daily-flow model was developed for reproducing historical flow data in the Cape Fear River basin, North Carolina, according to F. E. Arteaga. With a slight modification of input parameters the model can simulate daily flows at any point along the main channels, both under present conditions and with proposed reservoirs in place.

Applications of dye tracing

Dye tracing was used by L. A. Wagner and P. H. Hamecher to define the dispersion pattern and time of travel of effluent discharged into Cayuga Inlet at Ithaca, N.Y. The dye (Rhodamine-WT) was injected into the outfall pipe from the Ithaca sewage-treatment plant. Dispersion in the inlet was monitored by a fluorometer in a boat. At the end of 4 d the dye had dispersed as far as 1.6 km.

E. R. German measured the travel time of soluble substances in a 56-km reach of Shades Creek in Jefferson County, Ala., using Rhodamine-WT dye. Stream discharge ranged from about 110 l/s at the upper end of the reach to 650 l/s at the lower end. Travel time for the entire reach was 233 h for the leading edge of the dye cloud and 260.5 h for peak concentration. Velocities ranged from 0.13 km/h upstream to 0.37 km/h downstream below substantial waste-water inflows.

A. O. Westfall and E. E. Webber measured dispersion characteristics and travel times of potential point-source pollutants in a 170-km reach of the Tuscarawas River above its confluence with the Walhonding River in Ohio. The fluorescent-dye-tracer technique was used. For the whole reach, and at stream discharges near 50 percent on the duration

curve, the travel times for the leading edge of the dye cloud and for the peak concentration were 119 and 137 h, respectively. This information will be used by the Ohio Environmental Protection Agency to estimate DO recovery rates and travel times of accidental pollutant spills.

Estimating streamflow characteristics from channel size

Regional relations between streamflow characteristics and stream-channel size offer a promising alternative to available methods of estimating flow characteristics for ungaged sites, particularly in semiarid regions. Some agreement on standardization of methods was reached in April 1974 among about a dozen investigators. A summary of recommended practices with respect to flood characteristics was reported by H. C. Riggs (1974).

Reliability of flow estimates from channel size depends partly on the user's ability to recognize a suitable channel reach and the reference levels in that reach. K. L. Wahl set up a test in northern Wyoming to determine how consistently trained individuals could measure channel size for three different reference levels. Seven participants independently visited 22 sites and measured channel dimensions in sections of their choosing. Assuming the functional relation between a discharge characteristic, Q, and channel width, W, is $\log Q = f(1.5 \log W)$ and that the average $\log W$ from seven measurements is the best estimate of $\log W$ at a site, an average standard error of about 30 percent for discharge measurements was attributed to differences in width measurements alone.

E. R. Hedman measured width and average depth of the active channel cross sections to define relationships for mean annual runoff in six hydrologic regions in the Missouri River basin. Hedman has defined the relationship of 10-yr peak discharge to channel size for five hydrologic regions. Standard errors of these relationships range from 30 to 35 percent.

L. M. Shown related flood-peak characteristics to width and depth of ephemeral stream channels in southwestern Utah, northwestern Arizona, and southeastern Montana. For a given width, the peaks on Montana streams are an order of magnitude smaller than those on Utah and Arizona streams.

Statewide relationships for estimating peak-flow characteristics and mean annual flow from channel width have been developed by H. W. Lowham for Wyoming streams. The standard error of 47 percent is smaller than that for relationships estimated from basin characteristics.

A modified slope-area method for computing discharge in natural channels

Discharge of a stream may be computed from the slope of the water surface, the cross-sectional area, and an estimate of the roughness coefficient. This, the slope-area method, is widely used to compute flood-peak discharges from high-water marks. Reliability of a computed discharge depends largely on the roughness coefficient, which must be estimated. An analysis by H. C. Riggs showed that results of comparable accuracy can be obtained from area and slope alone in natural channels; a roughness coefficient is not needed because roughness and slope are related.

Velocity pulsation measurements

B. L. Neeley, Jr., reported that velocity measurements were made on the Mississippi River at Baton Rouge, La., when the discharge was 20,600 m^3/s. Velocity 2 m below the water surface was recorded continuously for 5 h at two locations. From these records, average velocities were computed for 5-min intervals beginning every 20 s during the 5-h period. Average velocities during the first 20 s, 40 s, 60 s, 80 s, 2 min, and 3 min of each 5-min interval also were computed. Standard errors of 3.1, 2.5, 2.2, 1.9, 1.5, and 1.0 percent, respectively, were obtained when the partial-period mean velocities were related to the 5-min mean velocities.

A mathematical model for density-stratified flows

E. R. Holley developed a mathematical model for computing steady-state flows in a rectangular channel connecting two stationary bodies of water with different elevations and densities. The model solves appropriate equations of motion for each of three possible regimes (one-layer undirectional flow, arrested-wedge undirectional flow, and two-layer two-way flow) and chooses a correct solution for given boundary conditions by a sequential elimination process. Numerical solutions of flow through culverts of the Great Salt Lake Causeway are in acceptable agreement with 49 field measurements. The computed flow is sensitive to errors in measurement of water-surface elevation.

Thermal loading models of natural streams

Nobuhiro Yotsukura (USGS) and W. W. Sayre (Univ. of Iowa) found that the steady-state two-dimensional mixing equation, derived earlier by Yotsukura and E. D. Cobb (1972) for uniform flows, can be extended to nonuniform flows with a small modification. Use of a natural coordinate system with the longitudinal axis parallel to a curved stream

axis provides a distance-correction coefficient, ranging around unity, that is entered into the equation. This analytical work explains why closed-form solutions to the Yotsukura-Cobb equation agree with tracer and thermal data for two-dimensional mixing observed in a number of meandering natural streams.

Levee erosion

The relative amounts of levee erosion caused by natural forces (wind-generated waves and floodflows) and by small-boat traffic were studied in the Sacramento-San Joaquin Delta, Calif., by J. T. Limerinos and Winchell Smith (1975). In the narrow channel of Georgiana Slough, which is subject to winter floodflows and to heavy summer boat traffic, about 70 percent of the energy dissipated annually against the levee was attributed to tractive stress, about 20 percent to boat-generated waves, and about 10 percent to wind-generated waves. In False River, a channel subjected to continual tidal action but relatively unaffected by floodflows, energy dissipated by boat-generated waves was shown to range from about 45 to 80 percent of the total, depending on wind-movement assumptions.

Flood-hydrograph synthesis

G. S. Craig, Jr., and J. G. Rankl developed a dimensionless hydrograph of storm runoff from 298 hydrographs on 28 small drainage basins in Wyoming. They tested its reliability by synthesizing hydrographs from peaks and volumes of observed events, including some events not used in its derivation, and by comparing the synthesized with the observed hydrographs; a close agreement was found. They also developed (1) equations for estimating flood-peak discharges and flood volumes (at recurrence intervals of 10, 25, 50, and 100 yr) from drainage-basin characteristics and (2) a relationship between flood volume and peak discharge. These relationships can be used with the dimensionless hydrograph to estimate design hydrographs at ungaged sites on Wyoming streams draining less than about 28 km².

Predicting summer runoff in the northern Cascade Range, Washington

L. A. Rasmussen and W. V. Tangborn (1976) developed a hydrometeorological method for predicting summer runoff from drainage basins in the northern Cascade Range. The method, based on a linear relation between winter precipitation and annual runoff, relates streamflow for a season beginning on the day of prediction to the spring storage (including snow, ice, soil moisture, and ground water) on that day. The spring storage is inferred from an input-output relationship based on winter precipitation and winter runoff. Some advantages of the method are: (1) Monthly distribution of the predicted summer runoff can be computed; (2) the altitude distribution of estimated potential runoff or storage can be inferred; (3) only existing low-altitude runoff and precipitation stations are used; and (4) snow surveys are not needed.

CHEMICAL, PHYSICAL, AND BIOLOGICAL CHARACTERISTICS OF WATER

Hydrogen-ion concentration in southern New Jersey stream

Fishkills in Oyster Creek, near Waretown, N.J., are attributed by J. C. Schornick, Jr., to rapid decreases in pH levels from a normal of about 4.2 to about 3.6. These decreases occur during periodic flushing of a surrounding swamp but are not related necessarily to rainfall; the time interval between rains seems to be more important than the amount of rain. There is a direct linear relationship between the swamp and the stream pH levels. The acidity is probably the result of the oxidation of sulfides to sulfate in the open waters of the swamp.

Nitrification in acidic streams

Results of studies in southern New Jersey by J. C. Schornick, Jr., and N. M. Ram showed that many streams that receive secondary sewage effluent are characterized by pH levels of 4 to 7. Because nitrification occurs ideally at a pH level of 8.5 and decreases rapidly at pH levels below 7.0, four acidic streams were investigated to determine the effect of stream acidity on nitrification. The effluent provided enough buffering capacity to enable nitrification to occur, although the degree of nitrification varied considerably from one stream to another. The NH^+, NO_2^-, NO_3^-, and bacteria curves showed that growth and decay increased with distance downstream.

Reaeration measurements in streams

R. E. Rathbun, D. J. Shultz, and D. W. Stephens used a nonradioactive-tracer technique to measure reaeration coefficients of a reach of West Hobolochitto Creek near Millard, Miss. Rhodamine-WT dye was used as the dispersion and dilution tracer. Ethylene was used as the tracer gas, and concentrations (μg/l) in water samples were determined by gas chromatography. Measured reaeration coefficients were within the range of coefficients predicted by other equations.

Nuclear magnetic-resonance spectroscopy of humic acid derivatives

Proton and carbon-13 nuclear magnetic-resonance spectroscopy has been used extensively for the elucidation of the chemical structure of organic compounds. In previous attempts to measure the nuclear magnetic-resonance spectra of humic acids, the investigators were unable to obtain spectra measurements because free radical concentrations in the preparations broadened absorption peaks so much that none of the peaks were detectable. In order to eliminate this problem R. L. Wershaw, D. J. Pinckney, and S. E. Booker prepared the methyl esters of the humic acid fractions, using a new methylation procedure which they developed. The proton nuclear magnetic-resonance spectra of these derivatives have well-defined absorption lines which can be used for structural interpretation. Also, preliminary results strongly indicate that it is possible to obtain measurements of carbon-13 spectra.

Sacramento River water-quality investigation

As part of an intensive water-quality study of the Sacramento River in California, physical, chemical, and biological constituents were measured at three locations at a site on the river. Measurements made periodically over two 24-h periods included those for water temperature, DO, pH, specific conductance, selected major ions, plant nutrients, and phytoplankton.

L. J. Britton and R. C. Averett reported that constituent concentrations were often erratic, but they did not differ significantly between locations during the same time period nor with depth at individual locations.

Regional distribution of nitrogen, phosphorus, and specific conductance studied in Florida surface waters

M. I. Kaufman and L. J. Slack mapped chemical-type and regional-distribution patterns of specific conductance of Florida surface waters (Kaufman, 1972; Slack and Kaufman, 1973). The five chemical types mapped in terms of dominant cations and anions are: (1) Calcium and magnesium bicarboate, (2) sodium bicarbonate and chloride, (3) mixed type, (4) sodium chloride, and (5) calcium and magnesium sulfate. Most surface waters in the State are of type 1 or type 3.

In studying nitrogen, phosphorus, and organic carbon distribution in Florida surface waters, Kaufman and J. E. Dysart observed that organic nitrogen is the dominant nitrogen species in most surface waters, whereas nitrate nitrogen is dominant in shallow ground waters. Other studies showed rainfall and atmospheric fallout to be important sources of both nitrogen and phosphorus.

Chemical and biological effects of sanitary landfill leachate

Although the sanitary landfill serving the towns of Catskill, Athens, and Cairo, N.Y., is operated carefully, leachate from the landfill is believed by T. A. Ehlke to have caused profound changes in the biology of a nearby stream, Bell Brook. The benthic invertebrates, Ephemeroptera, Trichoptera, and Heterodonta, that were in the affected reach are being replaced by Naididae and Tendipedidae. Concentrations of oxygen, nitrogen, and carbon and levels of pH in the affected reach of the stream have changed very little. The benthic invertebrate types in the stream are determined by the content of certain trace elements in ground water below the streambed. Iron and manganese are believed to be the most important trace elements affecting benthic invertebrates.

Inhibition of microbial plugging of laboratory columns

G. D. Ehrlich investigated the causes of plugging of experimental sand columns in the laboratory; plugging commonly occurs even when deionized water passes through washed sand. Certain bacteria and fungi can grow in these extremely dilute solutions and are sustained by traces of nutrients derived from the laboratory atmosphere and experimental apparatus. Plugging does not occur if adequate concentrations of mercury ions are present. Low levels of mercury ($5\times10^{-5}M$ Hg^{2+}) caused selective inhibition of slime-forming organisms, whereas mercury-tolerant organisms multiplied in large numbers in the columns containing deionized water. Plugging did not occur until the mercury concentrations were less than 5×10^{-7} M.

Mathematical model of a small stream

Chloride, sodium, and stable strontium were injected for 3 h at a constant rate into Uvas Creek, Calif., to determine transport processes in a small mountain stream. S. M. Zand, V. C. Kennedy, G. W. Zellweger, and R. J. Avanzino reported that comparison of field results with a simplified mathematical model of the experiment indicated the dominance of convection in the behavior of solutes in the stream. Concentrations of chloride and sodium can be closely simulated by the model, but strontium concentration cannot.

Specific surface area as an index of reactivity

D. W. Brown (D. W. Brown and J. D. Hem, 1975) used several laboratory methods to measure the specific surface areas of four different materials—a sand consisting mainly of feldspar grains, a volcanic ash, a kaolinitic clay, and a montmorillonite. The areas, ranging from 550 to 0.5 m^2/g, correlated well with the cation-exchange capacity of the material. It seems possible that surface-area measurements will provide a useful index of the extent to which river sediments and surfaces of subsoil and aquifer material may react with and retain or decrease movement of pollutants in introduced waste.

Prediction of stream temperatures in New England

G. D. Tasker and A. W. Burns (1974) have fitted periodic stream-temperature data from 27 stations in New England to a harmonic function with a period of less than 365 d to account for the winter period when stream temperatures are at or near 0°C. Regression analyses were used to relate characteristics of the harmonic function to mean basin altitude and station latitude. These generalized equations make possible the prediction of harmonic mean stream temperature and streamflow at any site in New England. Such information may be useful for general-purpose planning, reconnaissance, and site-comparison studies.

Stream-temperature study in Indiana

W. J. Shampine reported that periodic temperature data collected by the USGS since 1950 and by the Indiana State Board of Health since 1957 are being analyzed, using a simple harmonic-curve-fitting procedure. The percentage of stream-temperature variability explained by the harmonic function exceeds 80 percent for 293 of the 304 stations.

The Indiana State Board of Health collects temperature data every 2 weeks, whereas most USGS data are collected monthly. Comparison of the harmonic mean, amplitude, and phase coefficient, calculated using 43 stations common to both sources and having overlapping periods of record, showed no statistically significant differences that could be attributed to the difference in sampling frequency. On individual streams, however, the calculated values derived from the two harmonic relationships may have more than a 10-percent difference in harmonic mean and amplitude, particularly in streams near large urban areas.

RELATION BETWEEN SURFACE WATER AND GROUND WATER

Stream-aquifer modeling

Twenty-three sites on the alluvial flood plains of five major tributaries to the Ohio River in Kentucky were selected by P. D. Ryder (1974, 1975) in a study to determine aquifer characteristics. A pair of observation wells was installed in the alluvium at each site, and recorded ground-water levels resulting from the passage of a flood wave in the river were analyzed by computer to determine the ratio of transmissivity to storage coefficient. This ratio was helpful in selecting transmissivity and storage coefficients to be used in an iterative digital model together with streambed thickness and hydraulic conductivity, water levels in the river, and location of bedrock valley walls. The models were verified by comparing computed ground-water levels of a passing flood wave in the river with observed data.

The methods, successful at only three of the sites, resulted in the following values: The ratio of transmissivity to storage coefficient ranged from 4.5×10^4 to 3.2×10^6 m^2/d; transmissivity from 9.3×10^1 to 2.2×10^2 m^2/d; storage coefficient ranged from 3×10^{-5} to 6×10^{-3}; streambed hydraulic conductivity ranged from 1.6×10^{-4} to 1.0×10^{-1} m/d with a streambed thickness of 1 m; and recharge from the bedrock valley wall ranged from 0 to 1.3×10^{-2} m/d. Analyses were unsuccessful at 20 sites because (1) one or both wells did not penetrate aquifer material, (2) there was significant aquifer inhomogeneity between wells, or (3) a combination of very low storage coefficient and large transmissivity values prevented the determination of unique, best-fitting, theoretical type curves.

Bank storage

A significant volume of water is stored in the banks of Franklin D. Roosevelt Lake in northeastern Washington. Preliminary results from a computer model developed by T. H. Thompson for determining bank-storage volumes indicate that an additional 5 to 10 percent of the usable storage is in the banks. The usable storage is 6.25×10^9 m^3 between the normal operating-stage elevations of 368 m and 393 m.

The parameters of the model are being further refined by comparing the model results with water-budget residuals. The model will be used to determine the volume of additional water from bank storage that may be available under various operating conditions at Grand Coulee Dam. The water may be used

for on-site power generation and downstream benefits such as irrigation and power generation.

The model may be modified for use at other reservoirs in the Pacific Northwest where bank storage may be significant.

Ground-water emergence in trout-spawning areas in spring-fed ponds

In a study of the hydrology of spring-fed ponds and the hydrologic effects of trout-habitat improvement practices, W. J. Rose (USGS) and R. F. Carline (Wisconsin Department of Natural Resources) found a correlation between the location of redds (brook-trout spawning areas) and the rate of ground-water emergence. A portable device for measuring the rate of ground-water emergence through 0.255 m^2 of pond-bottom area was developed. Rates of ground-water emergence, which were determined by placing the device over redds, were found to be as much as 15 times greater than rates of ground-water emergence from nearby areas where there were no redds. These findings suggest that, in ground-water discharge areas, local heterogeneity of aquifer materials strongly influences the movement of ground water to points of emergence and that brook trout select places having high rates of ground-water emergence as sites for redd construction.

Surface-water—ground-water relationships in the Springfield, Missouri, area

Some streams in the Springfield, Mo., area have interrupted flow during the summer. To determine whether the water disappears into the channel fill and moves downstream within the fill or is lost to the underlying limestone, John Skelton and L. F. Emmett made seepage runs during the winter when the streams flow without interruption. Although winter base flows were large during the seepage runs, losses in certain stream reaches were identified and found to flow into the underlying limestone aquifer. These reaches are potential sources of ground-water contamination.

Artesian-aquifer recharge causes contamination of ground water

Results of a study by R. E. Krause indicate that the Withlacoochee River, flowing over a limestone sequence north of the city of Valdosta in southern Georgia, recharges the principal artesian aquifer with more than 850 l/s of water. During periods of low flow, the entire flow of at least 708 l/s discharges into the limestone aquifer. A southeasterly flow path of recharged ground water is indicated by measurements of water levels and field determinations of pH and conductance in water from a network of wells surrounding the recharge area. Downstream, where the head relationships are reversed, the aquifer discharges as much as 2,407 l/s of water to the river.

North of Valdosta, where flow is not maintained during periods of low flow, treated and untreated sewage effluent is discharged into the river and is undiluted until base flow from a shallower aquifer and the artesian aquifer enters the channel. Wells tapping the aquifer in the flow path of the locally recharged water are abandoned because of high organic color, which cannot be economically removed.

Decreasing ground-water recharge from canals in the Miami Springs-Hialeah area, Florida

F. W. Meyer (1972) and W. L. Miller found that infiltration from the Miami Canal system to major well fields in the Miami Springs-Hialeah area is decreasing as a result of a buildup of fine-grained sediments. Measurements of seepage losses from canals closest to the well fields during May 1973 indicated that only 50 percent of the average daily pumpage (4.5×10^5 m^3) was contributed by the canals. This was a decrease of about 8 percent over a 5-yr period. Ways to improve infiltration and prevent further decline in the water table are being investigated.

SOIL MOISTURE

An understanding of soil-moisture retention and movement is vital to the knowledge and control of our environment. USGS scientists are conducting field and laboratory investigations of the mechanisms involved in infiltration, evaporation, transpiration, and movement of water to the water table.

A soil-moisture model for predicting soil-water storage and use

Because of great fluctuations in annual and seasonal precipitation patterns, the use of soil-moisture models may permit closer approximations of soil-moisture storage and use than do periodic seasonal measurements of soil moisture. The model previously proposed by I. S. McQueen and R. F. Miller (1974) for approximating soil-moisture characteristics from limited data was further tested by McQueen, Miller, and F. A. Branson, utilizing moisture-content and moisture-stress data acquired from intensive field studies. Results indicate that water is adsorbed to the surface of soil particles as films and that these films become thicker as the soil becomes more moist. Water retained in contact angles by capillary forces apparently adheres to the adsorbed films. Evidence of capillary moisture ad-

hering to adsorbed moisture was obtained only at sites where capillary moisture was at equilibrium with a water table. Where no water table was present, evidence indicated that moisture was adsorbed only as films. This was true even at levels of stress usually associated with the capillary moisture-retention range. Field evidence of capillary rise was limited to somewhat more than 2 m. This coincides with the level of stress where quantities of water present in either the adsorbed or capillary state are equivalent. This equilibration occurs at a soil-moisture stress of approximately 2.24 m of water (22 kPa).

Evapotranspiration losses from stream channels

Phreatophytes along almost 2,000 km of stream channels in central Arizona were mapped to provide estimates of present and future evapotranspiration losses from these channels. The estimate of evapotranspiration will be based on a method of integration of the phreatophytes. Using the integration method for a reach of channel along Oak Creek, T. W. Anderson found that the estimate of consumptive use along the channel was in good agreement with that determined by a study of the base flow of Oak Creek near the Cornville gaging station. Several other sites are being investigated to determine the utility of the integration method. The baseflow analysis will be used again to check the results of the integration method.

Analytical solution for evapotranspiration rate from ground water

J. F. Daniel developed a type-curve solution for the constant rate of ground-water withdrawal by evapotranspiration; this is an extension of the work by M. I. Rorabaugh (unpub. data, 1975). The method uses streamflow hydrographs transformed to dimensionless time. Application of the method to a 1963 segment of the hydrograph for Indian Creek near Troy, Ala. (Coastal Plain), resulted in an evapotranspiration rate slightly less than 5 mm for a 30-d period during the months of May and June.

Use of reflectivity coefficient for heat budget in watershed model

J. F. Turner reported that a watershed model is being calibrated for several streams in west-central Florida. As in most watershed models, a measure of daily potential evapotranspiration is used as input. For many models, pan evaporation is normally used as a measure of potential evapotranspiration. However, for west-central Florida, only meager pan-evaporation data exist and therefore daily evapotranspiration values were calculated by use of a computer program based on H. L. Penman's (1948) equations.

In Penman's method, daily evaporation and a daily heat budget are required for computing potential evapotranspiration. Calculations of a daily heat budget require a reflectivity coefficient which is the ratio of reflected incoming radiation to total incoming radiation. The reflectivity coefficient, or albedo, is primarily a function of reflecting characteristics of the basin surface, angle of the rays of the Sun to the surface, and wavelength of the incoming radiation. Because of the regional variation of the surface, the reflectivity coefficient must be determined experimentally.

A reflectivity coefficient of 0.15 gave good results for the Tampa Bay area. The value was obtained by adjusting values of the reflectivity coefficient until simulated evapotranspiration agreed with basin evapotranspiration. Basin evapotranspiration was computed from long-term runoff and rainfall records.

A mass-transfer equation calibrated by pan evaporation in evaporation studies

Use of some mass-transfer equations for the purpose of measuring evaporation requires the determination of a coefficient. This can be done by measuring evaporation by the water-budget method or the energy-budget method while collecting the necessary data for the mass-transfer equation. However, determining the coefficient by the water-budget or energy-budget method is expensive and slow. Studies of Lake Michie and Hyco Lake, in North Carolina, indicate that pan-evaporation data may be used to determine the coefficient at less cost. G. L. Giese noted that although pan data converted to lake evaporation by a pan-to-lake coefficient do not give reliable results on a daily or monthly basis, they do provide reliable estimates on an annual basis. A pan-to-lake coefficient of 0.72 was found to be generally applicable in the Piedmont area of North Carolina.

Using lake evaporation data determined from the water-budget method, a coefficient was determined for the mass-transfer equation and compared to the coefficient determined from pan data. The values agreed within 12 percent, which is considered to be in the allowable error for evaporation studies in the Piedmont area. Hence, lake evaporation as determined over a long time interval (at least 1 yr) may be determined by multiplying nearby pan evaporation by the proper pan-to-lake coefficient (0.72 in the Piedmont section of North Carolina).

Using Harbeck's (1962) mass-transfer equation

$$E = Nu(e_o - e_a),$$

in which E = evaporation, in inches per day;
N = a coefficient of proportionality, called the mass-transfer coefficient;
u = wind speed, in miles per hour, at some height above the water surface; a numerical subscript, if used, indicates the height in meters;
e_o = saturation vapor pressure in millibars, corresponding to the temperature of the water surface;
e_a = vapor pressure of the air, in millibars; a numerical subscript, if used, indicates the height in meters,

the lake evaporation is set equal to the sum of the daily expressions of $Nu\ (e_o - e_a)$ over the same time interval. The coefficient N is the only unknown in this equation. Daily values of wind speed and vapor pressures were generated from measurements of wind speed 2 m above the water surface, water temperatures, and wet- and dry-bulb air temperatures. This method of calibration yielded an N coefficient of 0.000187 for Hyco Lake as compared to a coefficient of 0.000167 derived from the water-budget method of calibration. These two values are in reasonably close agreement (12 percent) and are considered equally accurate, but the pan-evaporation method of calibration is both much cheaper and faster.

EVAPOTRANSPIRATION

Evapotranspiration, the conversion by plants of water to vapor that is mixed with the atmosphere, accounts for the expenditure of approximately 70 percent of the 760-mm average annual precipitation in the conterminous United States. Because a large part of our water resource is being lost by evapotranspiration, measurements of the losses are very important for planning purposes.

Most of the significant results of evapotranspiration studies during the past year were from studies of stream channels and ground-water storage areas. Indirect methods of measurement, such as the water budget, were used in these investigations. Studies of indirect methods are continuously being made in order to improve their accuracy and to reduce their cost.

Relation of consumptive-use coefficient to the description of vegetation

The consumptive-use coefficient for the Blaney-Criddle evapotranspiration equation depends on vegetation characteristics. According to R. C. Culler, R. L. Hanson, and J. E. Jones, the basis for this relationship was found to exist when the measured evapotranspiration for the Gila River Phreatophyte Project in Arizona was compared to the conventional botanical survey. The survey includes species identification and canopy measurements which represent an integration of growth and transpiration characteristics during the life of a plant. Average seasonal coefficients have been calculated, but application of these coefficients is restricted to areas having similar seasonal climatic and environmental conditions to those of the project area.

A densitometric interpretation of repetitive color-infrared photography was developed for the project area to describe the spatial and temporal variability in foliation. The photographic measure of vegetation was related to the consumptive-use coefficient to provide a method of defining the seasonal variability in the coefficient by contemporary observations.

LIMNOLOGY AND POTAMOLOGY

Lake reconnaissance

Lake-reconnaissance surveys provide baseline information, identify problems for more intensive investigation, and form a basis for regional classification of lakes.

Reconnaissance limnological surveys in Pennsylvania at 52 recreational lakes were completed during the months of July and August between 1971 and 1974. In addition to providing a baseline of information for future hydrobiological investigations, the data will allow the lakes to be classified as to condition in compliance with Section 314 of Public Law 92–500. According to J. L. Barker, the surveys have disclosed that 18 of the 52 lakes display symptoms of, or the potential for, an enriched status. Because eutrophication of these lakes is due to natural and nonpoint sources of enrichment, control and restoration will be difficult.

Reconnaissance surveys by M. V. Shulters, Antonius Laenen, and J. H. Robison of 23 lakes in the high Cascade Range of northern Oregon showed the lake water to be of very high quality. The lakes range in size from 0.75 to 180 ha and dissolved-solids content is less than 60 mg/l; dissolved-solids content of 14 of the lakes is less than 20 mg/l. Light transparency,

measured by a Secchi disk, exceeded that of many smaller lakes; a maximum reading of 12 m was recorded in Lost Lake near Mount Hood. Lake sediments generally were unconsolidated and supported very little bottom vegetation. No fecal coliform bacteria were found in any of the lakes surveyed. During the September and October sampling period, thermal stratification was significant in only three of the largest lakes. The lakes surveyed are typical of many Cascade Range lakes; they were formed largely as a result of glacial or volcanic activity and are used primarily for public recreation. The several lakes that are protected within Portland's Bull Run watershed probably will remain in their present condition, but other Cascade Range lakes may receive greater recreational use in the future, which may result in water-quality changes.

G. A. McCoy collected chemical and physical data on Redoubt, Green, and Blue Lakes near Sitka, on Swan and Spurt Lakes near Petersburg, and on Osprey Lake near Port Walter, all in southeastern Alaska. The lakes are oligotrophic and, except for Redoubt Lake, conductivity was less than 50 μmho at 25°C. Nitrogen content was low and phosphorus content was generally less than 0.01 mg/l. DO exceeded 50-percent saturation at the bottoms of all lakes except Redoubt, which is meromictic. The upper 100 m of Redoubt Lake is freshwater and the lower 200 m is saltwater. The lower layer (monimolimnion) is anoxic. The upper layer (mixolimnion) of Redoubt Lake is well oxygenated and much higher in conductivity and dissolved-solids concentrations than the other lakes. It is high in sodium and chloride, probably owing to upward diffusion from the monimolimnion. Spurt, Swan, Blue, and Green Lakes have calcium bicarbonate type waters of very similar chemical composition. Osprey Lake, however, has a predominantly sodium chloride water, probably because of its high annual rainfall, low altitude, and proximity to the sea.

Data for 76 lakes with surface elevations ranging from 1,698 to 3,613 m were collected in the Front Range Urban Corridor, Colo., between lat. 38°37′30″ N. and lat. 39°22′30″ N. The lakes varied from stably stratified to thoroughly mixed, and water temperatures ranged from 6° to 24°C when sampled in midsummer. Secchi-disk transparency measurements were 1.2 m or less in six of the lakes but as much as 5.0 m in Mesa Reservoir. D. B. Adams reported that most of the lakes have water of good chemical quality. The range in specific conductance was from 25 μmho/cm at 25°C in Big Tooth Reservoir to nearly 1,100 μmho/cm at 25°C in an unnamed lake and pH levels ranged from 7.6 in Big Tooth Reservoir to 10.6 in Big Stratton Reservoir. DO as percent of saturation ranged from 68 percent in Big Johnson Reservoir to 186 percent in an unnamed reservoir.

Chlorophyll *a* concentration and phytoplankton were sampled in 13 of the larger lakes and reservoirs. Sixteen different genera of algae were identified as dominants or codominants in the lakes sampled; the most common were *Anacystis, Synedra, Cyclotella, Oöcystis,* and *Dinobryon.* Algal concentrations ranged from 380 to 57,000 cells/ml. All lakes sampled were rated for degree of organic loading by the algal index method of C. M. Palmer (1969). Only one lake, at Broadmoor Country Club, showed evidence of high organic loading on the basis of algal samples.

Relation of ground water to lakes

A preliminary hydrologic classification of lakes in the north-central United States was developed by T. C. Winter. Several forms of factor analysis were used to identify the independent factors that led to the most hydrologically meaningful classification system. In the principal component analysis, the first five factors account for 80 percent of the variance in the original 13 parameters. The loadings show factor 1 characterized by atmospheric water and chemical parameters, factor 2 by streamflow parameters, factors 3 and 4 by parameters that are related to ground-water flow, and factor 5 by overland runoff parameters. Maps of each of the five factors show distinctive patterns of areal variations within the study area. The statistical analysis is based on a random sample of 150 lakes.

Limnology of Lake Loíza

The chemical, physical, and biological characteristics of Lake Loíza, in Puerto Rico, were evaluated during a 1-yr period by Ferdinand Quiñones-Márquez. The quality of the water in the reservoir is affected by partially treated sewage and agricultural runoff. Total-nitrogen and total-phosphorus concentrations in the reservoir averaged 1.5 to 0.3 mg/l, respectively. Dense blooms of water hyacinths (*Eichornia crassipes*) occurred throughout the year. Transport of sediments by tributaries to the reservoir decreased light penetration, limiting blooms of microalgae. Phytoplankton communities were dominated by *Anacystics, Melosira,* and *Cyclotella.* Community productivity in the reservoir, measured by the diurnal oxygen curve, averaged from 3 to 12 g $O_2\,m^{-3}\,d^{-1}$. The dominant zooplankters were

species of *Macrocyclops, Paracyclops, Halicyclops,* and *Moina.* Vertical and diurnal fluctuations of the zooplankton were affected by low DO concentrations. DO varied seasonally with the intensity and magnitude of the lake turnover. During the low-flow season, most of the reservoir was anaerobic below 3 to 4 m. During the wet season, from September to December, DO concentrations of 2 to 3 mg/l were measured at depths of 10 to 12 m. Some thermal stratification occurred in Lake Loíza. During the winter months, top to bottom temperatures ranged from 24.5° to 28.0°C. In the summer and during high flows into the reservoir, nearly complete mixing occurred, and water temperature averaged 29.0°C. The bottom sediments of Lake Loíza contained an average of 2,000 mg/kg of total nitrogen and 850 mg/kg of total phosphorus. Bottom sediments were about 5 percent sand, 40 percent silt, and 55 percent clay. Nearly 10 percent of the upper 30 cm of sediments was organic matter.

Limnology of Laguna Tortuguero

A 1-yr study of the chemical, physical, and biological characteristics of Laguna Tortuguero, in Puerto Rico, was started in July 1974 by Ferdinand Quiñones-Márquez. The lagoon is a nearly freshwater body with an average specific conductance of about 2,500 μmho/cm at 25°C and an average chloride concentration of 800 mg/l. The lagoon is unstratified, has an average depth of about 2.5 m, and is constantly mixed by winds. The bottom is covered with a thick layer of sediment which is 6 to 8 m deep in some parts. The lagoon is affected by seawater flows from the zone of diffusion. Sea salts are present in concentrations proportional to seawater, but a canal discharges about 0.4 m^3/s into the ocean, maintaining a low salinity in the lagoon. The phytoplankton of the lagoon was dominated by *Anacystis* and other blue-green algae. The bottom of the lagoon was covered with a mat of periphyton, most of which were diatoms. There were more than 50 species of diatoms in the assemblage. The zooplankton was dominated by species of *Diaptomus, Testudinella, Keratella, Diaphanosoma,* and *Ceriodaphnia.* Total nitrogen and total phosphorus concentrations in the lagoon averaged 1.7 mg/l and 0.005 mg/l, respectively.

Initial limnological observations of Raystown Lake

D. R. Williams observed that during the first few months of water impoundment in Raystown Lake, Huntingdon County, Pa., no significant thermal or DO stratification occurred. At the time of these observations the lake elevation was at 233 m, about 3 m below the winter-pool elevation of 236 m and 7 m below the recreational-pool elevation of 240 m. Only in the upper, more shallow reaches of the 43-km-long lake was there evidence of anaerobic conditions on the lake bottom. In the deeper parts of the lake, approximately 5.6 km upstream from the damsite, DO concentrations as high as 7.6 mg/l were recorded on the lake bottom, 41 m below the surface, indicating that there had been no extensive decomposition of organic matter. Bacteriological data collected on the lower 23-km reach of the lake indicated very low concentrations of fecal coliform and fecal streptococcus bacteria. High flows from the main inflow feeding the lake increased the bacteria counts considerably in the upper 21-km reach of the lake but had little if any effect on the lower reach.

Diversity indices in water-quality studies

Diversity indices are used to summarize species-abundance tables and some other characteristics of biological systems. The most commonly used diversity index in water-quality studies is the one derived from J. L. Wilhm's and T. C. Dorris' (1968) information theory. Some shortcomings of using diversity and redundancy, its associated parameter, as unique indicators for the health of aquatic communities were found by S. M. Zand. Redundancy, *R*, as defined by Wilhm and Dorris (1966), is

$$R=\frac{H_{\max}-H}{H_{\max}-H_{\min}}$$

where $H_{\max}$ and $H_{\min}$ are maximum and minimum diversity indices using the Brillouin formula, while H is the diversity index using the Shannon equation. This intermixing of the two equations occasionally results in negative values for R. It is suggested that (1) biological sample collection and analysis be standardized prior to use or comparison of diversity index and its associated parameters among various aquatic systems and (2) if necessary, a more appropriate term be selected for redundancy, an expression in which Brillouin and Shannon equations are not arbitrarily intermixed.

Invertebrate drift in Alaskan streams

Drifting benthic invertebrates were collected at nine stream sites along the trans-Alaska pipeline route during 1972 by J. W. Nauman and D. R. Kernodle (1974). The samples were taken with drift nets, exposed for 1-h periods during daylight on three occasions designated as typical of spring, summer, and fall. Collectively, the dominant groups were

water fleas (class—Crustacea), midges (family—Chironomidae), blackflies (family—Simuliidae), and mayflies (order—Ephemeroptera). A total of 14,249 organisms were enumerated, and 86 taxa were identified from the 27 samples. Water fleas were dominant in an Alaskan North Slope stream, whereas midges were the most common invertebrate in a maritime stream near Valdez. From pooled samples for all three seasons at each site, brown-water streams had more species, whereas clear-water streams had greater species diversities. The midges were the most diverse, with 25 different taxa identified. Midges tended to be more diverse in Arctic Slope streams as compared to the other stream sites samples. Drift biomass was variable both seasonally and for different stream sites. However, biomass tended to increase during spring and fall, ranging from 0.06 to 3.0 g/h.

Comparison of sampling methods for benthic invertebrates

During a study of the Dietrich River, a mountain stream of arctic Alaska, K. V. Slack, J. W. Nauman, and L. J. Tilley compared the results obtained using the following techniques for collecting benthic invertebrates: (1) A 1-h drift-net collection was obtained at five upstream stations that had not been disturbed by other sampling. The net, held perpendicular to the flow, had an opening of 30×30 cm and 0.471-μm mesh. (2) A dip net with 0.210-μm mesh was used to sample the major aquatic habitats at the five stations. Sampling effort in each habitat was about in proportion to its occurrence at each station. (3) Ten streambed rocks were lifted at random from the major habitats, scrubbed with a brush in a bucket of water, and the combined sample was concentrated on a sieve with 0.210-μm mesh.

Most groups of organisms were more abundant and diverse in the dip-net samples. A few groups, notably certain shore-living insects (Collembola) and aquatic mites, were most abundant and diverse in the drift-net samples. Although the 10-rock samples were similar in composition to many of the samples taken with the dip net, the 10-rock samples were apparently too small to include some of the less abundant taxa. Collection of some midge (Chironomidae) larvae was more effective with the 10-rock method than with either of the other methods. The manner of scrubbing the rocks for the 10-rock sample may have resulted in more complete removal of small or burrowing larvae from rocks or masses of algae and moss. Because of the preponderance of Chironomidae in the Dietrich River benthos, the 10-rock method proved to be about as effective as the dip-net method in collecting benthic invertebrate individuals but only about half as effective in collecting the different taxa. More taxa were collected by the drift-net method than by the 10-rock method, and as many individuals were collected by the drift-net method as by the 10-rock method. Moreover, the drift-net samples contained many pupae, adult insects, and terrestrial invertebrates which did not occur in the other samples. The following conclusions resulted from the study: (1) The number of taxa collected from a station was increased when more than one method of sampling was used; (2) dip net effectiveness probably could be enhanced by more thorough scrubbing of rock surfaces to dislodge clinging or burrowing organisms; and (3) the value of a simple drift net as a passive collection method was shown. Finer mesh-size netting with an adequate percentage of open area should increase the effectiveness of drift sampling by retaining the smaller individuals.

Evaluation of artificial substrates for benthic invertebrates

Four types of artificial substrates—Bar-b-que basket, Bull basket, Flexiring, and Hester-Dendy multiple plate—were placed in the Eel River and Elder Creek near Branscomb, Calif. R. F. Ferreira studied the effects of artificial substrate type, sampling period (late spring to late summer), stream (river or creek), and habitat (pool or riffle) on benthic invertebrate colonization of artificial substrates. There was a significantly higher number of organisms and of different taxa on each of the four types of artificial substrates placed in riffles than were found in pools. However, diversity-index values did not show a significant difference in benthic invertebrates colonized between riffles and pools. Stream and sampling period had no effect on colonization of the artificial substrates. The main factor affecting colonization by benthic invertebrates was the artificial substrate type. A significantly higher number of organisms and number of taxa occurred on the Bull and Bar-b-que basket substrates than on the Flexiring and Hester-Dendy multiple-plate substrates. The difference was also shown by a significantly higher diversity index calculated for the Bar-b-que and Bull basket samples. However, the Bar-b-que basket substrate had advantages over the Bull basket; the Bar-b-que basket is easier to construct, can be placed on the stream bottom in any position, and does not fill with silt as quickly as the Bull basket.

PLANT ECOLOGY

Computer model predicts forest changes

A computer model is being developed by R. L. Phipps to simulate population dynamics of mixed stands of southern wetlands forests. The model, which is basically a tree-growth model utilizing average or typical growth characteristics of trees on site, is intended to be used as a tool for predicting vegetation change as a function of hydrologic change. It is being tested by Phipps, using data from the White River National Wildlife Refuge in southeastern Arkansas. A tentative conclusion is that relatively great changes in flood frequency and duration resulting from manmade flood-control measures may change the composition of tree species in undisturbed forests very little. However, any disturbance to the forest canopy, such as lumbering or managed enhancement of wildlife mast production, could be expected to result in pronounced changes in species composition.

Saltcedar establishment related to seed production and reservoir water levels

Field studies of three aspects of saltcedar (*Tamarix chinensis*) ecology were conducted in southeastern Arizona by R. M. Turner (D. K. Warren and R. M. Turner, 1975). Seed production, seedling establishment, and seed mortality from submergence were examined because of the important bearing each has on the spread of this species in the Southwest. Seed production in a dense stand of saltcedar yielded 17 seeds/cm^2 during the seed-producing seasons. During the 5.5-mo period of seed production there was one major production peak and one minor production peak. Seed production of two native riparian species, seepwillow (*Baccharis glutinosa*) and cottonwood (*Populus fremontii*), was studied and compared with saltcedar seed production.

The rate of establishment of saltcedar seedlings on the banks of a reservoir with receding water levels corresponded closely to the rate of seed production of nearby plants. The period of greatest establishment occurred between early May and mid-June; 47 seedlings were found in one 6-cm^2 area.

Mature saltcedar plants were able to survive complete submergence for as long as 70 d. Plants that were not completely submerged survived longer periods of flooding—the maximum was 98 d.

Natural reforestation less on coal strip mines than on abandoned farmland

T. M. Yanosky and R. S. Sigafoos compared natural reforestation of coal strip-mine spoils in southeastern Kentucky to that on nearby abandoned farm fields. They estimated that abandoned-farmland plots yield about four times as many trees per acre as do mine-spoils plots. On the farmland, crown density of pine trees is nearly twice that on the spoils and the total cross-sectional area of tree trunks is seven times greater. The lesser quantity of vegetation on the spoils is probably related to poorer site conditions; there are greater distances between trees on mine spoils than between the same species of trees on farmland.

NEW HYDROLOGIC INSTRUMENTS AND TECHNIQUES

G. F. Smoot and H. O. Wires reported that 12 operational models of a streamside, multiparameter, automatic water-quality monitor are giving excellent service and additional units will soon be in use.

Wires reported that an automatic orifice-purge capability added to field stage-recording manometers has increased the accuracy of records at alluvial streamflow sites.

According to Wires, digital data-collection systems installed at big-dam field sites have been modified to improve reliability and system flexibility.

Wires also reported that specifications have been drafted and a bid has been accepted for additional satellite hydrologic data-collection platforms to be used with LANDSAT or with GOES.

Three automatic storm-water data-collection systems have been installed in northern Broward County, Fla. The data-collection systems were developed by USGS personnel to simultaneously record rainfall and storm-sewer flow and to collect multiple water-quality samples throughout a storm event. According to C. B. Sherwood, Jr., and Jack Hardee, sample collection will continue for 2 yr at each of the three sites. Sites selected for study are a single-family residential area, a segment of six-lane divided highway, and a major shopping center.

A. M. Sturrock, Jr., and H. E. Jobson reported that radiation data were recorded continuously at two southern California field sites about 26 km apart. Solar radiation was sensed at both sites by Eppley precision spectral (shortwave) pyranometers. Atmospheric radiation was sensed at one site by an Eppley (longwave) pyrgeometer and the total (all-wave) radiation was sensed at the other site by a Beckman-Whitley flat-plate radiometer. The atmospheric radiation at the flat-plate radiometer site was determined to be the difference be-

tween the instantaneous all-wave and the instantaneous shortwave components. On a daily average basis, both instruments gave results which appeared to be of comparable accuracy, and the measured values of the longwave component agreed reasonably well with values computed from formulas. On an instantaneous basis, the Eppley pyrgeometer gave results which agreed fairly well with the computed longwave values. The ratio of the mean maximum output to the mean minimum (nighttime) output was stable in the range of 1.3 to 1.4. The measured flat-plate radiometer values, on the other hand, appeared to be too low at night and too high during the day. The ratio of the mean maximum output to the mean minimum output was 3.5 for the 35 days analyzed. This ratio decreased somewhat with increasing cloudiness.

W. S. Keys is making logs of holes deeper than 1,372 m, using a logging truck which has a large hoist unit with 4,877 m of high-temperature 7-conductor cable. Keys reported that the following field-proven high-temperature probes are now being utilized in geothermal studies: (1) Temperature, (2) natural gamma, (3) gamma-gamma, (4) neutron, (5) caliper, and (6) normal resistivity.

Keys also reported that acoustic televiewer logs were used to interpret the results of a hydraulic fracturing test in a geothermal well in New Mexico and to identify sources of hot water in test holes in Idaho.

I. L. Burmeister reported that the Mississippi River at Clinton and Keokuk, Iowa, is being sampled with the use of a special boom mounted on a garden tractor. The standard USGS base-and-boom rig could not be used at the Keokuk site because of a confined 81-cm-wide sidewalk. The special rig, designed by Burmeister, consists of a davit-type boom with a type E–53 power reel mounted on a model VH70, 7-hp-John Deere garden tractor. The maximum width of the tractor is 69 cm. The alternator on the tractor provides sufficient charge to the 12-V battery of the tractor to operate the power reel and safey light. An extra Hot Shot battery is required to operate the 45-V solenoid of the P–61 sampler. A case of sediment bottles is strapped on the hood. The rig is towed on a small, low-bed trailer to a site; the operator then drives it onto a bridge and takes samples. It is also used on bridges without sidewalks. Its 8-km/h speed and its flashing safety light make it easier, faster, and safer to use than a standard base-and-boom rig. Also, the rig has been used to make complete discharge measurements.

J. V. Skinner and J. P. Beverage tested some newly developed commercial instruments for sampling and for analyzing sediment. In one flume study a small pumping sampler was used to extract samples from the flow. Samples were then compared with siphoned samples extracted through the same intake tube. The intake tube passed through the flume wall and extended 5 cm into the flow. Angled downstream to shed debris, the intake extracted samples at nearly right angles to the flume flow. Under adverse conditions (3-m vertical lift, battery-power mode) the pump maintained velocities of approximately 60 cm/s in the 0.6-m intake line. This velocity proved to be adequate for transferring particles from the mouth of the intake to the discharge side of the pump. The sediment concentration in the test suspension consisted of Missouri River sand; 95 percent of the material was finer than 400 μm and 5 percent was finer than 62 μm with D_{50} of 180 μm. Compared to samples extracted isokinetically, both pumped and siphoned samples were lower in sediment concentration, but this deficiency was a characteristic of the intake and not of the pumping sampler itself. To reduce cross contamination of samples, the sampler was designed to backflush with air, but the tests revealed that in long horizontal runs, traces of sediment did remain in the intake line. More serious errors were caused by deposition within the sampler's distributor system, which routes samples from the pump to sample containers. However, the sampler proved to be very reliable, and its small size and battery-powered feature make it attractive for use at sites where the bulk of material in suspension is silt and clay.

A laboratory-based particle sizer was evaluated for routine laboratory analysis. A sample was illuminated by a rotating laser beam which detected light scattered by suspended particles, and the pulses were used to count and size individual particles. Concentrations as low as a few parts per billion were detected, but drift was too large to permit size-distribution measurements.

In cooperation with J. M. Killen (Univ. of Minnesota), Beverage and Skinner tested a modification of the falling-drop technique. In this technique, a single drop of test suspension is placed in an immiscible liquid; the fall velocity of the drop is measured and, by calibration, the sediment concentration within the drop is determined. Anisole was used for the immiscible liquid in the original development work performed by J. M. Pezzetta (Univ. of Wisconsin). Because anisole is quite toxic, a special instrument oil was substituted for anisole in

the modified technique. With very precise temperature control, the lower limit of detection was found to be about 200 mg/l.

Beverage and Skinner constructed a special hydrometer for rapid measurement of concentration. With temperature controlled to within ±0.5°C, the lower limit of detection was about 50 mg/l.

USGS investigators, in cooperation with R. H. Rust (Univ. of Minnesota), are evaluating a commercial optical size analyzer. Particles are first deposited on a membrane filter which, through chemical treatment, is rendered transparent. By means of an electronic scanner and microscope, particles are automatically counted and classified by size. Results are encouraging, but the relationship between particle weight and registered particle size requires additional study.

Beverage and Skinner made a preliminary evaluation of errors in sampling through nappes at the free outfall of a narrow channel. To date, the range of conditions studied has been limited to outfall flows 30 cm wide and 10 cm deep. A DH-48 sampler was used to collect depth-integrated samples a few millimetres downstream from the lip. The sampler's air exhaust was completely ventilated in the shallow flow, and this effect, combined with adverse approach conditions, reduced the sampler's intake velocity by about 10 percent. The material in transport was Missouri River sand in suspension. For each run the sampling error was based on the difference between sediment discharge computed from sample concentrations and sediment feed rate measured at a vibrating feeder that injected sediment into the flow 8.8 m upstream from the outfall. The mean sampling error was 0.5 percent with a standard deviation of 13 percent. Additional tests would probably reveal a larger mean error, but the existing data do not suggest a serious systematic sampling bias. Results of these tests are applicable to field sampling at culvert outfalls. Results show that a number of closely spaced verticals must be sampled even if the nappe width is narrow. Because of the 30-cm outfall-flow width, a minimum of three vertical samplings was necessary to adequately account for the large concentration gradients in the lateral direction. Also, in the laboratory as in the field, collection of precise discharge-weighted samples is difficult. The problem stems largely from shallow depth and high velocity. For most accurate results, the sample from each vertical should be analyzed separately. This permits an assessment of the magnitude of the gradients, and then, if necessary, the concentrations can be discharge weighted in the computational phase. Unfortunately, this computation requires a knowledge of velocity distribution with the nappe. The investigators hope to extend the study to a wider range of conditions, and, by making additional runs within each group, strengthen the statistical significance of the conclusions.

COMPUTER PROGRAMS FOR MODELING AND SOLVING HYDROLOGIC PROBLEMS

R. S. Chicko developed a computer program that solves for porosity and lithology, given digitized acoustic velocity, density, and neutron porosity logs. The computer program formulates the lithology problem as a linear-programming model and then solves this model by the simplex method. The computer program has many advantages over previously attempted approaches, such as cross-plot techniques and the solution of simultaneous linear equations. The linear-programming formulation does not permit negative solutions and, thus, ends a long-standing problem. Also, the computer program is able to solve more unknowns than previous numerical techniques. Because the computer program incorporates statistical analyses of core data, the computed solutions are forced to conform with actual lithology.

Chicko and T. A. Taylor developed a system to generate a multiplexed data base for condensed storage and rapid access to digitized borehole geophysical logs. Logs made with the research equipment are digitized in the field on magnetic or punched tape. Existing analog records may be digitized commercially. Digitized data are input, stored, processed, and summarized for a reference library and rapid computer interpretation.

SEA-ICE STUDIES

Many advances have been made in using remote-sensing techniques to study the morphology and dynamics of sea ice, and the resulting data are being applied to numerical models of pack ice. Remote-sensing techniques have been used in recent sea-ice experiments, and results have been highly successful.

Remote-sensing studies of sea ice

Results derived by W. J. Campbell (D. C. Meeks, R. O. Ramseier, and W. J. Campbell, 1974) from a comparative study of 13.4-GHz passive-microwave surface measurements of physical, chemical, and structural properties of Arctic sea ice illustrate distinct decreasing microwave emissions for first-year,

transitional, and multiyear sea-ice types. There is a structural relationship for microwave emissions by transitional and multiyear sea ice. Both vertically and horizontally polarized measured brightness temperatures decrease linearly with increasing average ice porosity. In first-year ice, however, measured brightness temperatures are comparatively uniform and microwave emission appears to be more strongly influenced by high near-surface salinity combined with the occurrences of uniform porosity. Another study (R. O. Ramseier, W. J. Campbell, W. F. Weeks, L. D. Arsenault, and K. L. Wilson, 1975) involved the use of LANDSAT imagery acquired over a 1-yr period to study in detail the ice dynamics and morphology of parts of the Arctic Ocean and the Canadian Archipelago. The use of remote-sensor imagery to describe one complete cycle of ice freeze-thaw processes and drift patterns saved an enormous amount of time, expense, and manpower.

Joint U.S.-U.S.S.R. Bering Sea Experiment

The joint U.S.-U.S.S.R. Bering Sea Experiment (BESEX) took place in February and March 1973 and involved both Soviet and American aircraft, the U.S. Coast Guard icebreaker, *Staten Island*, and the Soviet weather ship, *Priboi*, in a detailed remote-sensing study of the Bering Sea. A NASA aircraft, the *Galileo*, was equipped with cameras and passive-microwave and infrared radiometers for imaging the morphology and distribution of sea ice in the Bering Sea. According to W. J. Campbell (W. J. Campbell, Per Gloersen, and R. O. Ramseier, 1974; Per Gloersen, R. O. Ramseier, W. J. Campbell, P. M. Kuhn, and W. J. Webster, Jr., 1974; R. O. Ramseier, Per Gloersen, W. J. Campbell, and T. C. Chang, 1974; Per Gloersen, R. O. Ramseier, W. J. Campbell, T. C. Chang, and T. T. Wilheit, 1974), the following five distinct ice types were discernible: (1) Gray ice, 20 cm thick; (2) gray-white ice, 40 cm thick; (3) white ice, 60 cm thick; (4) white and first-year ice, 100 cm thick; and (5) transition-zone ice (frazil, grease, and small pancake ice). Most of the pack ice is formed in the Bering Strait. The pack ice is entirely first-year and younger, and during the experiment its concentration ranged from 74 to 90 percent within a roughly constant geographic area of approximately 10,000 km^2. Anticyclonic activity in the area advected the ice southward with strong divergence and a regular lead and polynya pattern; cyclonic activity advected the ice northward with ice convergence, or slight divergence, and a random lead and polynya pattern.

Skylab–4 photographs used for floating-ice studies

In addition to data which were collected by the instruments comprising the Skylab Earth Resources Experimental Package (EREP), the Skylab–4 astronauts obtained photographs, taken by hand-held cameras, of target areas designated for floating-ice studies. The main objective of the study was to gather information on sea ice in the Gulf of St. Lawrence and lake ice in Lake Ontario. The Skylab–4 crew obtained photographs of sea ice in the Bering Sea, the Sea of Okhotsk, and James Bay and of large tabular icebergs in the South Atlantic. W. J. Campbell (W. J. Campbell, R. O. Ramseier, W. F. Weeks, and J. A. Wayenberg, 1974) reported that the sequential photographs provided very useful information on distribution of ice and ice types, overall deformation patterns, and amount of ice movement between flows.

ANALYTICAL CHEMISTRY

Spectrofluorometric determination of thallium in silicate rocks

A sensitive spectrofluorometric procedure to determine submicrogram and microgram quantities of thallium in silicate rocks was developed by M. M. Schnepfe (unpub. data, 1975). Samples are decomposed with a mixture of hydrofluoric and nitric acids and then treated with hydrochloric acid. Thallium is extracted as the dithizonate from an alkaline medium containing ascorbate, citrate, and cyanide salts by using chloroform and is then back-extracted with dilute nitric acid. The organic matter is destroyed, and the sample is treated with bromine, hydrochloric acid, aluminum chloride, and rhodamine B. The rhodamine B chlorothallate is extracted with benzene, and its fluorescence is compared with standards. With this procedure, 10 ng Tl in pure solution can be determined with a relative standard deviation of 5 percent; the determination limit is thus set at approximately 10 ng for a 1-g sample. The thallium content of USGS standard rocks G–1 and W–1, according to duplicate determination with this procedure, is 1.09 ± 0.01 μg/g Tl.

Determination of trace amounts of bismuth

W. H. Ficklin and F. N. Ward used an atomic absorption spectrophotometer equipped with a graphite furnace to determine trace amounts of bismuth down to 10 ng in soils and rocks. This analytical technique can be used to differentiate crustal abundance levels of bismuth from enrichment levels to outline targets of mineral deposits of possible economic importance.

Enhanced sensitivity of a spectrophotometric germanium determination

L. P. Greenland, in continuing studies of the germanoheteropoly acid complex of molybdate, developed the most sensitive known color reaction of germanium. A tributyl phosphate-cyclohexane extraction of the yellow heteropoly acid yields a molar absorptivity of 21,000 at 310 nm in comparison with values of 2,400 and 9,100 cited by Sandell for the yellow and the blue heteropoly acids, respectively, and a value of 14,500 for the germanium phenylfluorone complex. Interferences are removed prior to the determination by extracting the $GeCl_4$ with CCl_4 or with C_2Cl_4 with equal efficiency. The latter extraction technique has the advantages of lower volatility and toxicity. A working range of 0.1 to 1 μg Ge is obtained in a 5-ml volume by using a 5-cm light path.

Rock analysis procedures revised

In a revised USGS Bulletin, Leonard Shapiro (1975) described rapid methods of analysis for 16 major constituents. Spectrophotometric methods are used for SiO_2, Al_2O_3, Fe_2O_3, TiO_2, P_2O_5, and MnO, whereas CaO, MgO, Na_2O, and K_2O are determined by using atomic absorption spectrometry; H_2O^+, H_2O^-, FeO, CO_2, F, and S are determined by other techniques.

ISOTOPE DILUTION

Rapid determination of lead in rocks

P. J. Aruscavage developed a substoichiometric isotope dilution method for the rapid determination of lead in rocks. After acid decomposition of samples containing 1 to 5 μg Pb in the presence of Pb^{210} tracer, lead is extracted with dithizone and reacted with a substoichiometric amount of ethylenediamine tetraacetic acid. Lead content is calculated from the specific activity of the complex after removal of excess lead with dithizone. Results obtained with standard rocks show excellent precision and accuracy in comparison with isotope dilution-mass spectrometry.

Determination of nanogram amounts of silver

A rapid procedure for the routine determination of nanogram amounts of silver in rocks was described by E. G. Lillie (1975). After dissolution of the sample with a hydrofluoric-nitric-perchloric acid mixture in the presence of Ag^{110} tracer, the silver is separated by (1) extraction as the dithizonate into xylene and (2) back-extraction into dilute hydrochloric acid. After evaporation and removal of the hydrochloric acid, the silver is taken up in an acetic acid-sodium tartrate buffer solution and reacted with a constant amount of radioactively labeled iodide. The silver iodide formed is isolated by extraction into amyl alcohol, and silver is determined by the ratio of the counting rate of the iodide to the counting rate of the silver in the silver-iodide complex. The method can determine as little as 0.005 μg/g Ag in 0.5-g sample.

ACTIVATION ANALYSIS

A semiautomated processing technique for analysis

A computerized semiautomated system for processing samples by instrumental neutron activation analysis was completed when P. A. Baedecker wrote the computer program to generate a printed summary of analytical results. This program, now in use, produces a printed report that lists concentration and sigma based on counting statistics for Fe, Ba, Co, Cr, Ca, Hf, Rb, Sb, Ta, Th, Zn, Zr, Sc, La, Ce, Nd, Sm, Eu, Tb, Yb, and Lu. This procedure eliminates the need for typing a report. Sample changes permit the multichannel analyzers to automatically collect gamma-ray spectra onto magnetic tape, after which the gamma-ray data are computer-processed to determine the concentrations. When more than one gamma-ray peak is used for the calculations, the program provides a weighted average for the concentration to be reported. Concentration data are transferred to a disk for collation with additional counting data for the samples. Data are finally taken from the disk and processed to provide the final report of the analysis.

Radiochemical determination of low concentrations of nickel in rocks and minerals

R. A. Zielinski (unpub. data, 1975) developed a radiochemical procedure for the determination of very low concentrations of nickel in rocks and minerals. Accuracy and precision are estimated to be ± 5 percent to levels as low as 0.1 μg Ni. Sensitivity is 0.1 μg Ni. These values represent a marked improvement over possible competing analytical techniques. Samples are irradiated, combined with a nickel carrier, and treated by a series of purification procedures including collection of nickel in a lead bead by means of a fire assay technique; refusion of the lead bead and precipitation of basic element hydroxides; washing and dissolution of precipitate; and anion exchange chromatography and precipitation of nickel dimethylglyoxime. The precipitate is weighed to determine chemical yield and counted for beta activity along with a precipitate from an irradiated nickel standard solution.

Fission-track technique for the measurement of uranium in solutions

A fission-track procedure for the determination of uranium concentrations in aqueous solutions was tested by R. A. Zielinski. A standard and a sample solution (1.0 ml) and submerged squares of low-uranium fused-quartz glass are heat sealed in lengths of polyethylene tubing and irradiated for up to 4 h at a neutron flux of 2.5×10^{12} n/cm²/s. The glass platelets are recovered and etched for 1 min in 48 percent HF to develop fission tracks. Track densities produced by the samples and the standard are determined by microscope observation and compared. Track densities are linearly proportional to uranium concentrations over the investigated range of 100 ng/g to 100 μg/g. Uranium concentrations as low as 10μ/g can be measured by this technique. Corrections must be applied for solutions with U^{238}/U^{235} ratios differing from the natural ratio.

EMISSION SPECTROSCOPY

Improved accuracy in computerized emission spectrographic analysis of geologic materials

The transport and excitation of atomic vapors in the d-c arc plasma determine the time-integrated spectral line intensities that are measured by computerized emission spectrography. These processes must be similar for samples and standards to assure accurate analyses for elements in the samples. D. W. Golightly, C. P. Thomas, A. F. Dorrzapf, Jr., and C. S. Annell (1975) investigated these processes for more than 60 constituent elements in diabase, granite, andesite, peridotite, and shales by means of automated microphotometry and computerized data processing. Intensities, integrated over the arcing time, for major constituent elements are found to be similar.

A calculator program for quantitative spectrographic analysis

A. L. Sutton, Jr., wrote a program for either the Wang 520 or the Wang 600 calculator to make all the calculations required for quantitative spectrographic analysis. This program has subroutines for both the Crosswhite-Deike and the ASTM 2-step emulsion calibration methods, a second-degree fit for analytical curves, and subroutines to evaluate the polynomials and calculate the final analytical results for samples. Provisions are also made for dilution factor and background corrections. The minimum machine requirements are 1,848 program steps, a printer, and a tape cassette unit. The program is available in the form of magnetic tapes and instructions directly from Sutton.

High-resolution gamma-ray spectrometer for uranium-series isotope studies

A recently developed high-resolution gamma-ray spectrometer permits identifications, in the laboratory and in the field, of several uranium-series isotopes that are not resolved by conventional detectors. The planar intrinsic germanium detector, developed by R. M. Moxham, permits detailed examination of the 10- to 200-keV gamma- and X-ray region, where many closely spaced spectral lines from the uranium-series nuclides are found. In high-grade ore, these include ^{238}U, ^{235}U, ^{234}Th, ^{231}Th, ^{230}Th, ^{226}Ra, ^{223}Ra, ^{214}Pb, and ^{210}Pb.

The preliminary studies in the laboratory indicate that uranium can be determined quantitatively independent of the state of secular equilibrium and that the state of equilibrium can be measured for some members of the series. The amplitudes of these peaks in low-grade material have yet to be determined.

Borehole logging with a neutron activation probe

A nuclear marine probe was constructed by using a ^{252}Cf neutron source and a Ge(Li) detector cooled by a prefrozen propane canister technique developed in the physics laboratory in Reston, Va. The probe was used to test the feasibility of making in-place captive gamma-ray spectrometry measurements in bottom sediments in a marine environment. Chlorine causes serious interferences in the spectra and an energy hardening of the average neutron flux density, so that pure thermal neutron capture is not attained in practice.

ANALYSIS OF WATER

Aluminum species in solution

Aluminum hydroxide particles small enough to pass a 0.1-μm-diameter-pore filter may occur in natural water. Dissolved-aluminum concentration values used in thermodynamic calculations should not include these aluminum species. R. B. Barnes (1975) found that only the ionic forms of aluminum are determined if a complexing agent (oxine) is added to the sample at the time of collection, and the sample is immediately extracted with methyl-isobutyl ketone.

Selenium

An atomic-absorption spectrophotometric method for determining selenium in water was developed

by Myra Lansford, E. M. McPherson, and M. J. Fishman (1974). The method involves evolution of hydrogen selenide by reduction of selenite with stannous chloride in 6-*M* hydrochloric acid solution. The hydrogen selenide is subsequently swept from the sample solution by a stream of nitrogen into a hydrogen flame and its absorption is measured at 196 nm. Arsenic interference can be avoided by careful control of the amount of stannous chloride added. Mercury interference occurs when its concentration exceeds 25 μg/l. As little as 1 μg/l of selenium can be measured. Incorporation of preliminary digestion of a sample ensures decomposition of organic selenium compounds.

Nitrogen compounds

The use of a Technicon aluminum-block digestor to decompose organic nitrogen compounds in water samples was evaluated by D. E. Erdmann and found to be satisfactory for determining ammonia plus organic nitrogen. Forty samples are digested simultaneously during a 2.5-h heating period on an electric hotplate; only 20 ml of sample is required. The digested sample is cooled and adjusted to proper volume, and the resultant ammonium salts are determined by an automated procedure involving the colorimetric reaction of ammonium ion with sodium salicylate, sodium nitroprusside, and sodium hypochlorite in an alkaline solution. As little as 0.1 mg/l of ammonia plus organic nitrogen can be determined by this procedure.

Ferricyanide and thiamine

M. C. Goldberg and J. K. Wilson found that ferricyanide or thiamine in water can be determined by measuring the fluorescence of the complex formed between these two compounds. Several substances, including cyanides, interfere. Cyanide interference can be prevented by complexing with silver ion.

Neutron activation analysis

The carrier-sulfide radiochemical separation used in the neutron-activation analysis of water sometimes gives erratic results for arsenic, antimony, and zinc. L. L. Thatcher modified the procedure by using thioacetamide and introducing new elements into the carrier; as a result, recovery of arsenic, antimony, zinc, and 14 other elements improved, and there was less sodium contamination. The technique was used to analyze snow samples from Denver, Colo.; aluminum, copper, and manganese were found, possibly correlating with certain aspects of urban pollution. The technique was also applied to investigations of interactions between dissolved metallic ions and sediment particles.

GEOLOGY AND HYDROLOGY APPLIED TO THE PUBLIC WELFARE

EARTHQUAKE STUDIES

GEOPHYSICAL STUDIES

Seismicity

The USGS program of earthquake monitoring in the seismically active southern California region continued to expand in 1974 with the installation of a 27-element seismograph network in the Mojave Desert. D. P. Hill and G. S. Fuis reported that results thus far support earlier indications that most of the seismic activity occurs in the western half of the Mojave Desert (west of long 115°30′ W.). A swarm of local earthquakes, several of them larger than magnitude 4, occurred in August 1974 near the Pisgah fault just outside the northern margin of the Mojave net. Composite first-motion plots indicate right-lateral strike-slip motion on a plane parallel to the northwest-trending Pisgah fault.

The southern Alaska seismic net continued to expand its coverage, and, with the installation of 19 new telemetered stations in the Yakataga seismic gap by E. E. Criley, M. E. Blackford, R. A. Page, and G. E. Loo, the total number has now been increased to 51. This region, between Prince William Sound and Yakutat Bay, has not experienced any great earthquakes since the 1899 and 1900 magnitude 8+ earthquakes, and, during the past 15 yr, only a small number of earthquakes have been located in this region by distant worldwide seismic stations. Microseismic activity recorded there since network installation in September 1974 has been low relative to that recorded in the Prince William Sound and Cook Inlet regions. Two biaxial borehole tiltmeters were installed by C. E. Mortensen, M. J. S. Johnston, and Page on Middleton Island, at the western margin of the seismic gap. Preliminary data indicate active tilting of the island.

J. C. Lahr and Page used the local net supplemented by teleseismic data to delineate the extent and configuration of the Benioff zone beneath southern Alaska. The upper part of the zone has a low dip and extends up to 400 km northwest of the Aleutian trench, then steepens and descends to a depth of 150 to 200 km, and reaches as far north as the northern foothills of the Alaska range.

J. D. Unger and P. L. Ward made a careful study of the seismic *P*-wave travel-time residuals from the April 26, 1973, magnitude 6.2 earthquake off the northwestern coast of Hawaii in order to infer upper mantle structure beneath the Hawaiian Islands. The 30 USGS stations on Hawaii permit precise location of the quake and the determination of its origin time. These measurements, in turn, allow a determination of very accurate absolute travel times to more distant stations. Differences between observed and expected travel times give clues to the structure beneath Hawaii, and it appears that *P*-wave velocities are abnormally low in the upper mantle beneath the island of Hawaii or to the southwest of it.

W. H. Bakun and C. G. Bufe reported that body-wave spectra from central California earthquakes recorded at local stations have shown large spatial variations in attenuation and propagation path characteristics. Shear-wave attenuation coefficients differ by at least a factor of 3 between propagation paths in the San Andreas fault zone and those in the Gabilan Range to the west of the fault.

A. C. Tarr and K. W. King used data from a new 10-station seismographic net installed in South Carolina in 1974 to survey the seismicity and help assess the earthquake hazard in that State. Preliminary results from a local five-station network in the Charleston-Summerville region indicate microearthquake activity in the area of the destructive 1886 Charleston earthquake. Elsewhere, seismicity is scattered in small local clusters, and, at present, there is no evidence for a northwest-trending zone from Charleston to the Appalachians, as has been postulated by several previous investigators.

S. W. Stewart and L. B. Nichols developed a time-shared interactive graphics computer system to speed up the daily analysis of earthquake waveforms. The system uses a low-cost storage-tube-type computer graphics terminal connected by telephone line to a large-scale computer. Earthquake waveforms are

read into the computer from magnetic tapes. By typing in simple commands at the keyboard, the scientist may display and manipulate two or more earthquake waveforms at a time. A key feature of the system is that it allows the scientist to interact and guide the processing of each earthquake waveform through the computer.

Earthquake prediction

The USGS central California seismic net, now comprising 132 stations, was used increasingly in 1974 as a research tool in earthquake prediction experiments designed to detect possible seismic-wave velocity changes prior to moderate local earthquakes. R. L. Wesson, Russell Robinson, C. G. Bufe, W. L. Ellsworth, J. H. Pfluke, and J. A. Steppe reported changes in *P*-wave velocity measured by observing travel paths from local earthquakes through the zones of two imminent earthquakes, one of magnitude 4.6 and the other of magnitude 5.0. In addition, for three other events between magnitudes 4 and 5, anomalously deep microearthquake activity was observed prior to the shocks.

J. H. Healy and colleagues have been carrying out an intensive experiment in the Bear Valley, Calif., region to determine crustal structure of the San Andreas fault zone and to search for seismic velocity changes preceding earthquakes. The experiment supplements the central California network stations with a very dense portable array of up to 100 stations, which are telemetered by radio or by hard wire back to a single tape recorder. Results obtained thus far indicate that velocity changes, if they exist, are either small or at considerable depth in the fault zone. The portable system that has been developed for this experiment will also be useful in other detailed seismological investigations, such as the exploration of geothermal areas.

Bufe, Pfluke, and Wesson found that the mean apparent focal depths of microearthquakes occurring along a 20-km stretch of the San Andreas fault southeast of Hollister, Calif., increased by 25 percent some 60 days before the magnitude 4.6 Stone Canyon earthquake of September 4, 1972. The shape of the time-depth anomaly is virtually identical to the time plots of V_p/V_s preceding moderate earthquakes at Garm in the U.S.S.R. A less well defined depth anomaly occurred from October to December of 1971, preceding the Limekiln Road earthquake swarm of December 1971 and the magnitude 5.0 Melendy Ranch earthquake of February 1972. The observed depth anomalies can be attributed to dilatancy biasing of hypocenters, although true vertical migration of seismicity cannot be ruled out.

Using an array of fourteen 2-component borehole tiltmeters located near the San Andreas fault in central California, M. J. S. Johnston and C. E. Mortensen learned some details of the form of crustal deformation associated with small to moderate strike-slip earthquakes ($M=2.5$ to 5). To date, precursors in tilt magnitude and direction have been observed before more than 10 earthquakes or groups of earthquakes, and no similar effect has yet been seen without the occurrence of an earthquake. Installations in other tectonic settings (Alaska and southern California) are providing data to test models of the earthquake mechanism developed with data from the central California test section.

A magnitude 5 earthquake on Thanksgiving Day, 1974, in the midst of the heavily instrumented central San Andreas fault zone near San Juan Bautista provided the first observations of several different types of precursory signals for the same earthquake. Both tilt and magnetic field precursors were observed, and a possible preearthquake velocity decrease is also currently being investigated.

Laboratory experiments by J. D. Byerlee provided observations relevant to several mechanisms proposed to account for precursory earthquake phenomena. Byerlee observed that under differential stress the permeability of granular materials is anisotropic, this condition introducing an additional complication into precursory mechanisms requiring fluid flow. However, it was also observed that prefailure velocity changes may occur even if the rock is dry throughout the strain cycling.

Crustal strain studies

J. C. Savage and W. H. Prescott analyzed geodetic data in the region of the 1872 Owens Valley, Calif., earthquake in order to determine the current rate of strain accumulation there. Right-lateral deformation since 1934 across the valley is occurring at a rate of 4 ± 1 mm/yr, with possible extension across the valley of 1 ± 1 mm/yr. Repeated level surveys show tilts equivalent to a 2.2 ± 0.4-mm/yr uplift of the western edge of the valley (that is, the base of the Sierra Nevada scarp) relative to the center of the valley. Although the measured deformations are scarcely above the survey noise, they all indicate an accumulation of strain that would be consistent with a repeat of the 1872 earthquake.

W. R. Thatcher examined the approximately 100-yr record (1860–1960) of triangulation surveys on

the northern San Andreas fault system in order to reconstruct the history of crustal deformation in this region. High rates of shear straining preceded and followed the 1906 San Francisco earthquake, and data are consistent with an accelerated slip deep on the fault plane prior to the earthquake and a post-earthquake relaxation immediately beneath the seismic zone following 1906. However, since about 1940 and perhaps earlier, faults to the east of the San Andreas have played an important role in the strain accumulation: within the data uncertainties, straining is uniform across an 80-km-wide region to the east of the San Andreas fault in the San Francisco Bay area; the maximum shear strain direction is approximately parallel to the Calaveras fault and is distinctly different from both the strike of the San Andreas fault and the local direction of relative motion between the Pacific and North American plates. North of San Francisco, the rate of strain accumulation appears to decrease.

R. O. Burford, R. D. Nason, and P. W. Harsh used data from the central California seismic net and creep meter records for 1969–73 to estimate the ratio between the total computed seismic slip and the total observed surface creep along the central San Andreas fault. In the currently most seismically active section of the fault, 70 km southeast of San Juan Bautista, surface creep exceeds seismic slip by at least a factor of 30; ratios for other less seismically active segments of the fault average 1 to 2 orders of magnitude lower.

Seismic risk and earthquake hazards reduction

Analyses completed by 16 researchers in various Earth-science and engineering disciplines and using existing geological and geophysical knowledge suggest that seismic zonation in the San Francisco Bay area is feasible (R. D. Borcherdt, 1975). Summary results derived as basic tools for this regional zonation include the following:

1. R. L. Wesson, R. D. Brown, Jr., E. J. Helley, K. R. Lajoie, and C. M. Wentworth completed a map showing active faults and delineating areas of potential surface faulting (that is, the location of potential sources of strong ground shaking).
2. R. A. Page, D. M. Boore, and J. H. Dieterich collected attenuation data for bedrock shaking and made estimates of peak ground motion parameters at bedrock sites located at distances greater than 10, 20, and 40 km from earthquakes of magnitude 5, 6, and 7, respectively.
3. Lajoie and Helley compiled geologic data that provide the basis for extrapolating results of local site studies to larger areas. The purpose of this work is to define and map groups of geologic units significant for ground response, liquifaction, and slope stability.
4. Borcherdt, W. B. Joyner, R. E. Warrick, and J. F. Gibbs prepared a map showing qualitative ground response and delineating those areas for which site amplification of ground motion is expected to be important.
5. T. L. Youd, D. R. Nichols, Helley, and Lajoie prepared a liquifaction potential map showing areas in which existent clay-free granular layers have a low, moderate, or high potential for liquifaction.
6. T. H. Nilsen and E. E. Brabb completed a landslide susceptibility map that classifies areas into five categories of relative slope stability on the basis of landslide deposit distribution, bedrock geology, and slope.

These six basic tools were applied along a demonstration profile for a postulated magnitude 6.5 earthquake on the San Andreas fault to illustrate a methodology for seismic zonation of the San Francisco Bay area.

S. T. Algermissen and colleagues M. G. Hopper, C. J. Langer, and A. M. Rogers prepared maps showing the estimated distribution of Modified Mercalli intensity in the regions of Salt Lake City, Utah, and Puget Sound, Wash., for earthquakes of magnitude 7.5 and 7, respectively.

A. F. Espinosa and Algermissen surveyed the damage and distribution of intensity resulting from the October 3, 1974, magnitude 7½ earthquake in Lima, Peru. They find a correlation between the dominant period of the earthquake and the damage sustained by high-rise structures.

Joyner and A. T. F. Chen developed a new method for calculating the earthquake response of one- and two-dimensional soil configurations that rigorously treats the nonlinear hysteretic behavior of soils. Comparison with the widely used equivalent linear method indicates that, for a thick soil column and strong earthquake excitation, the equivalent linear method significantly underestimates the short-period components of motion.

Algermissen and D. M. Perkins completed a preliminary seismic risk map for all of the continental United States except California. The map depicts horizontal ground acceleration having a 10 percent probability of being exceeded in 50 yr (475-yr return

period peak acceleration). This kind of risk map reflects economic risk better than previous maximum intensity maps, which do not explicitly take earthquake occurrence rates into account. For example, three areas, each appearing in zone 3 (maximum risk high intensity, heavy damage expected), now have the following extreme accelerations: Charleston, S.C., 0.1 to 0.2 *g*; New Madrid, Mo., 0.2 to 0.4 *g*; and western Nevada, 0.4 to 0.6 *g*.

GEOLOGIC STUDIES

Possible active fault in Ventura

R. F. Yerkes and A. M. Sarna-Wojcicki mapped a prominent linear topographic scarp about 10 km long and up to 12 m high trending east-west along the hill front immediately north and east of Ventura, Calif. This feature is inferred to be a fault-line scarp formed by reverse-oblique displacement on a north-dipping frontal fault because:

1. It is located at the steep southern front of one of the east-trending Transverse Ranges, directly analogous to the scarp of the San Fernando fault, and on trend with a known active fault, the Pifas Point fault, previously mapped for more than 20 km in the eastern Santa Barbara Channel, where it displaces Holocene deposits but not the sea floor and has an apparent vertical separation of about 25 m up on the north.
2. The hill front immediately north of the scarp is underlain by uplifted, tilted, and faulted upper Pleistocene marine and nonmarine terrace deposits.
3. Steeply dipping older Pleistocene strata of the hill front locally exhibit tight folds having near-vertical axes.
4. Larger drainages are deflected at the scarp.
5. At one locality, a well-developed, buried (Sangamon?) soil with a thick oxidized B horizon is sharply flexed just north of the scarp and is not present south of it. At another locality, a younger soil is less sharply flexed near the scarp; since this latter soil is developed in a Holocene(?) fan, its deformation may reflect Holocene movement at depth.
6. The scarp cannot be explained by erosion related to present-day drainage. The scarp is modified by erosion, cultivation, and construction and locally may be buried by very young stream deposits. Although unequivocable evidence of Holocene displacement has not been found, the fact that the scarp postdates the emergence of a low marine terrace in this area of continuing seismicity indicates that its age and activity should be thoroughly investigated.

Holocene movement on the Garlock fault

The Garlock fault, a major left-lateral fault in southern California, trends northeast to east for a distance of about 250 km. Its total displacement is estimated to be about 65 km. The fault trace provides abundant evidence of geologically recent activity, but no historic displacements have been recorded. Where its trace lies along the southern edge of Searles and Panamint Valleys, alluvial and lacustrine sediments of late Quaternary age are offset. Near Christmas Canyon in Searles Valley, stratigraphic and geomorphic relations noted by G. I. Smith suggest that two horizontal displacements totaling 8 m have probably occurred during the last 10,000 yr. The fault in that area consists of a single trace that has a zone about 15 cm wide dipping steeply to the south. The older of the two displacements cuts lacustrine gravels estimated to be 10,000 yr old or older and was probably covered by alluvial gravels, estimated by stratigraphic correlation with dated subsurface sediments to have ceased deposition 6,000 to 8,000 yr ago. The younger of the two displacements cuts those alluvial gravels but is covered by others that are probably a few hundred but not more than about 2,000 yr old.

Along the southern end of Panamint Valley (30 km east of the Christmas Canyon area), the Garlock fault last displaced a thin alluvial unit tentatively correlated with deposits in Searles Valley estimated to be about 2,000 yr old. If displacements in both areas occurred at the same time, these relations suggest that the next-to-the-last offset occurred 6,000 to 10,000 yr ago and that the last offset occurred between a few hundred and 2,000 yr ago. The sum of the two horizontal displacements is 8 m. If the last displacement were so recent that little or no strain has accumulated, the implied rate of strain accumulation is 0.8 mm/yr. However, if the last displacement occurred at about the same time that the younger alluvial gravels were deposited (about 2,000 yr B.P.), then the implied rate of strain accumulation would be $\geqq$1 mm/yr.

Late Quaternary faulting in coastal California

Mapping of Quaternary features along the San Mateo County coastline by K. R. Lajoie, G. E. Weber, and J. C. Tinsley III documented the type and age of movements along a major fault zone that branches off the San Andreas fault at Bolinas Lagoon north

of the Golden Gate and extends 150 to 200 km south-southeast subparallel to the California coastline. In the vicinity of Point Sur, south of Monterey, it is represented by the Palo Colorado fault. The fault zone lies offshore for most of its length but transects the San Mateo County coastline for 4 km north of Half Moon Bay, where it is called the Seal Cove fault, and for 26 km between San Gregorio and Point Año Nuevo, where it is called the San Gregorio fault. Deformed emergent marine terraces record general movements to about 0.5 to 0.7 m.y. B.P., and deformed Holocene deposits document very recent displacement. Seismic activity along the seaward extension of this fault zone south of Point Año Nuevo documents modern activity.

Four strands of the San Gregorio fault zone, exposed in the sea cliffs on the southern shore of Point Año Nuevo, offset the Sangamon wave-cut platform and the overlying marine and alluvial deposits of the first emergent terrace, this offset indicating movement in the last 70,000 to 140,000 yr (Weber and Lajoie, 1974). Northwest of Point Año Nuevo, tectonic movements associated with the San Gregorio fault zone have tilted a series of at least six emergent marine terraces. Successively greater terrace deformation with age suggests continued movement during middle to late Pleistocene time with northwest tilting of the block west of the main strand of the San Gregorio fault zone. Stratigraphic offsets and the pattern of faulting indicate that most of the movement along the fault zone is right-lateral strike slip with smaller and variable vertical components associated with internal deformation of the blocks within and on either side of the fault zone.

Holocene movement is indicated on one of the fault strands at Año Nuevo by deformation of fluvial and estuarine deposits along the shear zone. Charcoal from a deformed bed of silty clay in these deposits yields a ^{14}C age of 9,510±140 yr B.P.

Gentle folding and vertical fault offset of emergent marine terraces at Half Moon Bay record late Pleistocene tectonic movements along a 23-km segment of the Seal Cove fault and its offshore extension to the south, which joins the San Gregorio fault. The wide, continuous lowest terrace (Sangamon?) and the discontinuous second terrace are warped successively more tightly into a gentle syncline that plunges obliquely to the northwest into the fault zone. Linear joint-controlled stream courses draining the coastal uplands are deflected toward the synclinal axis as they cross the lowest terrace. Streams crossing the downwarped part of this terrace adjacent to Half Moon Bay are depositing alluvial fans, whereas streams crossing the uplifted part of the terrace south of the bay have incised and abandoned their late Pleistocene flood plains, which themselves are incised into the thick cover of marine terrace deposits. Half Moon Bay developed as the Holocene transgression flooded the synclinal trough formed in the lowest terrace (Lajoie and others, 1975).

North of Half Moon Bay, the lowest terrace is offset vertically 45 m (west side up) across the Seal Cove fault to form the narrow linear Pillar Point headland and ridge. North of Half Moon Bay, discontinuous remnants of at least four higher marine terraces are offset vertically along five short fault strands subparallel to and northeast of the Seal Cove fault. Evidence of recent tectonic activity is a 0- to 1.5-m west-facing scarp across the Holocene alluvial fan of Denniston Creek parallel to and 1.0 km northeast of the Seal Cove fault.

Data on marine terraces along the entire western coast of the United States being compiled by B. R. Hamachi and P. A. McCrory will serve as the basis for an expanded coastal tectonics project. Data on tectonic movements recorded in the deformation of late Pleistocene emergent terraces and in the regional variability of deposits formed by the Holocene transgression probably can be integrated with and provide background for other coastal tectonic projects, such as regional studies of active faults by J. I. Ziony, J. M. Buchanan-Banks, and E. H. Pampeyan and studies of present crustal movements using geodetic and tide-level data by R. O. Castle.

Field studies related to the preparation of geologic environmental maps of coastal California have verified the existence of late Quaternary faulting in two areas where information was previously lacking or little known. One area, between the Newport-Inglewood fault in southern California, was defined by Ziony, C. M. Wentworth, Buchanan-Banks, and H. C. Wagner (1974) on a 1:250,000-scale map designed to show the tectonic environment of coastal southern California from Mexico to Point Arguello. A second area lies near San Luis Obispo, in central coastal California, where detailed geologic mapping by C. A. Hall, Jr. (1973a, b, 1974), and reconnaissance by Pampeyan defined a northwesterly trending zone as much as 2 km wide and 120 km long, in which Pleistocene deposits are offset. The Edna fault, a west-northwest-trending fault with probable strike-slip displacement, is near the southern end of this zone. At the northern end is an unnamed set of northwest-trending lineaments, evidenced onshore

near San Simeon by several prominent parallel valleys, along which stream channels are offset in a right-lateral sense. Offshore, this set of lineaments appears to control the coast between Cape San Martin and Point Estero. However, with the offshore data presently available, no simple clear-cut connection can be found. If the ends do not define a single continuous zone of strike-slip faulting, they are at least parts of a larger system along with the offshore Hosgri fault. The geometry and tectonic environment in this area are significant in land-use planning, because tectonic elements in the zone are close to (less than 12 km) a proposed deepwater supertanker port facility and a nuclear powerplant.

Seismic response studies in San Francisco Bay region

Geologic maps of upper Quaternary unconsolidated deposits in the San Francisco Bay region by E. J. Helley and K. R. Lajoie provided the basis for interpreting and extrapolating seismic velocity data (*P* and *S*) in a study to predict how each geologic unit in the alluviated flatlands will respond in a local earthquake and how the entire alluviated area will respond relative to the surrounding bedrock terrane.

Results of a preliminary study by J. F. Gibbs, R. E. Warrick, T. E. Fumal, R. D. Borcherdt, Lajoie, and L. T. Youd showed that the average seismic velocities (*P* and *S* in metres per second) over a 0- to 30-m depth interval range from 1,500 and 90, respectively, for the Holocene Bay mud to 1,670 and 380 for saturated upper Pleistocene alluvium, to 1,850 and 490 for Pliocene sandstones, to 2,700 and 275 for greenstone of the Franciscan Formation (Cretaceous part), and to a maximum of 3,900 and 1,450 for the deeply weathered granodiorite of Montara Mountain. Results to date indicate that shear-wave velocities correlate with seismic amplitude responses determined from nuclear explosions and the 1906 earthquake intensities. Preliminary data indicate that the differences in seismic velocities and engineering properties between Holocene and upper Pleistocene alluvium are significant only where these units lie above the water table. Upper Pleistocene alluvium in the lower parts of the bay basin, adjacent to and beneath the bay, probably has never been dessicated and therefore shows no signs of preconsolidation. In higher parts of the alluvial plain surrounding the bay, upper Pleistocene alluvium has probably been above the water table throughout much of its history and is therefore preconsolidated. In these areas, overlying Holocene alluvium is not yet preconsolidated, so its physical properties are different from those in the upper Pleistocene alluvium. Test sites are being selected to investigate the role of depth to ground-water table on seismic response characteristics.

History of recent movement on the Elsinore fault

Recent field investigation by M. M. Clark (1975) showed that right laterally offset drainages occur at several places along the 150-km section of the Elsinore fault zone that lies in Imperial and San Diego Counties. However, fault-offset topographic features are either greatly eroded or missing entirely from much of this southeastern part of the fault zone. Only in a 15 km-long section at the common county line does the fault show the impressive continuity of very recently offset alluvial surfaces and channels that is typical of active parts of the San Andreas and San Jacinto faults. Southeast of this section and northwestward through Mason Valley, the fault zone is marked by either well-eroded or very discontinuous horizontal and vertical offsets of the ground surface. Northwest of Mason Valley, most of the remaining 70 km of the fault zone in San Diego County is characterized by fault topography that either no longer preserves the amount of original offset or is entirely of erosional origin rather than tectonic origin.

In the 30-km interval immediately northwest of the common county line, recent movement has occurred only along a subparallel group of normal faults that lie 3 to 4 km to the northeast of the projected trend of the otherwise straight Elsinore fault zone.

This spotty distribution of evidence for recent movement along the southeastern part of the Elsinore fault zone, combined with the presence of active faults to the northeast between the Elsinore and San Jacinto fault zones, suggests that recent release of crustal strain in this region has complex distribution and, perhaps, timing. Release of strain is not concentrated uniformly along the southeastern part of the Elsinore fault zone.

Earthquake recurrence intervals from deformational structures in young lake sediments

Examination of the silty sediments in the Lower Van Norman Reservoir after the 1971 San Fernando, Calif., earthquake revealed three zones of deformational structures in the 1-m-thick sequence of sediments exposed over about 2 km^2 of the reservoir bottom. These zones are correlated with moderate earthquakes that shook the San Fernando area in 1930, 1952, and 1971. The success of this study, coupled

with the experimental formation of deformational structures similar to those from Van Norman Reservoir, led to a search for similar structures in Pleistocene and Holocene lakes and lake sediments in other seismically active areas. Thus, studies have been started by J. D. Sims in Pleistocene and Holocene silty and sandy lake sediments in the Imperial Valley in southeastern California, in Clear Lake in northern California, and in the Puget Sound area of Washington.

The Imperial Valley study has yielded spectacular results: five zones of structures in the upper 9 m of upper Holocene sediments of ancient Lake Cahuilla near the Imperial fault 3 km south of Brawley have been correlated over an area of approximately 100 km^2 by using natural outcrops (Sims, 1974). These structures are similar to those of the Van Norman Reservoir and are interpreted to represent at least five moderate to large earthquakes that affected the southern Imperial Valley area during late Holocene time. Eleven holes were drilled and sampled continuously in these ancient lake sediments. The holes range in depth from 11 to 26 m and extend the knowledge already gained from limited outcrops at least threefold. Examination and analysis of these cores are now underway.

The Clear Lake study has provided ambiguous results with respect to the determination of earthquake recurrence intervals because the cores studied are in clay-rich organic sediments that have low liquefaction potential (Sims and Rymer, 1975).

A study of upper Pleistocene varved glaciolacustrine sediments has been started in the Puget Sound area of Washington, and 13 sites have been examined. One has yielded 18.75 m of sediments that contain 1,804 varves and 14 deformed zones interpreted as being caused by earthquake because they are identical to structures formed experimentally by simulated seismic shaking. These structures have been used to construct a preliminary earthquake history for the Shelton, Wash., area (Sims, 1974). This history shows two episodes of earthquake activity. The first period of earthquake activity lasted about 400 yr and consists of six subequally spaced earthquakes. A second episode lasted about 900 yr and consists of five subequally spaced earthquakes.

Correlation of deformation structures with seismic events is based on (1) proximity to presently active seismic zones; (2) presence of potentially liquefiable sediments; (3) similarity to structures formed experimentally; (4) small-scale internal structures within deformed zones that suggest liquefaction; (5) structures restricted to single stratigraphic intervals; (6) zones of structures correlatable over large areas; and (7) absence of detectable influence by slopes, slope failures, or other sedimentological, biological, or deformational processes.

Metagraywacke in the Salinian block—recantation and reevaluation

Field studies by D. C. Ross showed that the metagraywacke terrane in the Santa Lucia Range of California is intruded along its western side by Mesozoic granitic rocks. Thus, Ross's previous suggestion—that the western contact of the metagraywacke marked a significant strike-slip fault zone—must be abandoned.

Nevertheless, this lithologically distinctive belt in the Salinian block, extending across Salinas Valley, is structurally significant as a "barrier" against strike-slip movements in the area and thus counters a previous suggestion of Ross and Brabb (1973). The metagraywacke also limits strike slip on the northern extension of the Rinconada fault zone of Dibblee (1972).

The metagraywacke belt and other bedrock relations in the Gabilan and Santa Lucia Ranges suggest a coherent basement block without significant strike-slip displacement from the San Andreas fault west as far as the Palo Colorado fault on the western flank of the Santa Lucia Range. Anyone proposing models of Salinian block reconstruction should note that "slivering" of the Salinian block at this latitude, or continuation northward of the Rinconada strike-slip fault zone, must occur west of this block.

Influence of bedrock structure on seismicity

Analysis of the San Andreas fault system in central and northern California by W. P. Irwin resulted in the discovery of a close relationship between regional geologic structure and seismic behavior. "Locked" fault segments have little seismic activity between occasional earthquakes of large magnitude, whereas other segments are highly active and are characterized by frequent earthquakes of small magnitude and by creep. The principal locked segment is the main strand of the San Andreas fault from near San Juan Bautista northward to beyond Point Arena; a second locked segment extends southward from Cholame. The active segments include (1) the San Andreas fault southward from near San Juan Bautista to Cholame and (2) the Sargent, Calaveras, and Hayward faults in the San Francisco Bay region.

The significant aspect of the regional geologic structure is the remarkably close correlation between the truncated end of the upper plate of the Coast Range thrust and the zones of creep and frequent small-scale seismicity along the San Andreas, Hayward, and Calaveras faults. The faults tend to be highly active where they regionally cut the upper plate, which consists of rocks of the Great Valley sequence, but they are locked elsewhere. In this structural model, serpentinite, which occurs locally along the base of the Great Valley sequence, is in contact with the segments of the faults that cut the upper plate and is perhaps plastically injected and sheared along the faults by right-lateral drag.

Another possibly related factor affecting seismicity is the distribution of springs in the Franciscan metamorphic terrane, which Irwin studied jointly with Ivan Barnes. Where Franciscan rocks are capped by the upper plate of the Coast Range thrust, water from metamorphic rocks may migrate to the faults that cut the upper plate; this water may fill and lubricate the fractures in dilated rocks and thereby cause continuous creep rather than allow large strains to accumulate. The terrane cut by the principal locked segment of the San Andreas fault in northern California is devoid of springs that derive water from metamorphic rocks.

Fault scarp morphology as a key to age

R. E. Wallace's study of historic and older fault scarps in north-central Nevada, such as those formed during the 1915 and 1954 earthquakes and those formed before and after the high stand of glacial Lake Lahontan (12,000± yr), showed progressive degradation accompanied by a decrease in maximum slope angle. Historic scarps have two major slopes: the upper slopes (free faces) range from 60° to overhanging, whereas the lower slopes (debris slopes) have maximum angles of about 35°. In some places, the two different slopes may persist for more than 1,000 yr. The maximum slopes of scarps older than 12,000 yr are concentrated in the 7° to 20° range, and those of scarps younger than 12,000 but older than a few thousand years are in the 15° to 35° range. Other characteristics, such as the curvature of the scarp crest and the ratio of free face to debris slope, are also age criteria.

Analysis of scarp geomorphology indicates repeated movement on some faults, such as the 1915 earthquake fault, and suggests recurrence intervals for major displacements measured in thousands of years.

ENGINEERING GEOLOGY

Slope stability investigations

What is probably the largest known landslide in the United States caused by lateral spreading (a result of liquefaction) was discovered 16 km north of Salt Lake City, Utah, by Richard Van Horn. Two such landslides occur in Davis County, Utah, between Farmington and Great Salt Lake and comprise the area named the Farmington Siding landslides. The younger slide covers about 9 km^2 and is probably less than 2,000 yr old. The older covers at least 8 km^2 and is between 2,000 and 5,000 yr old. An unknown amount of the older landslide lies hidden under the younger.

The Farmington Siding landslides contain longitudinal ridges, undrained depressions, and distinctive internal structures indicating sliding, shearing, and liquefaction. A preliminary version of a new topographic map of Great Salt Lake and vicinity revealed seven other areas around the lake that have topographies similar to the topography of the Farmington Siding landslides. Thus, landslides of this type may be common near Great Salt Lake, and land users and land-use planners should develop an awareness for potential landslides on the gently sloping plains surrounding Great Salt Lake.

Reports from the 1906 San Francisco earthquake and other northern earthquakes were reviewed, and incidents of ground failure described therein were identified, classified, and tabulated and their locations plotted on modern maps by T. L. Youd and S. N. Hoose. The results were used to (1) further identify and clarify the types of ground failure associated with earthquakes; (2) provide a guide to engineers, planners, and others responsible for minimizing seismic hazards; and (3) form a data base for further geotechnical studies of earthquake-triggered ground failure.

Liquefaction-induced lateral spreading of recent flood-plain deposits and filled areas, particularly in the city of San Francisco, is among the most common and most destructive types of ground failure triggered by earthquakes in northern California. Hillside landslides on steep slopes, such as coastal bluffs, also are a very common and very destructive type of ground failure.

Continued studies by D. H. Radbruch-Hall of the gravitational creep of rock masses indicate that large-scale slope movement of this type may be widespread in the United States, especially in mountainous regions. This type of slow landsliding, in which

zones of creep can extend more than 100 m below the surface, is distinct from more well-known types of movement of surficial material, such as solifluction and debris flows.

Since large-scale gravitational creep may change to sudden catastrophic slide movement, recognition and understanding of this phenomenon are vital in site selection for and design of major engineered structures, particularly in high mountains. In places where valley sides are moving horizontally or bulging outward, engineered structures in the valley bottom will be subjected to both upward and lateral pressures, owing to the bowing up of the valley bottom or the closing in of the sides.

Large-scale rock creep on slopes has been observed and described by various investigators, including Radbruch-Hall, in different parts of the world: Europe, New Zealand, Iran, South America, and the United States. Measured rates of such movement range from 2 cm/yr to 20 cm/d.

Creep proceeds in several different ways in different geologic settings: (1) By valleyward extrusion of weak ductile rocks overlain by, or interbedded with, more rigid rocks, resulting in tension fracturing and outward movement of the more rigid rocks as well, sometimes with upward bulging in the centers of valleys; (2) by distortion and buckling of dipping, interbedded strong and weak rocks or by creep of rigid rocks over soft rocks without buckling; (3) by movement distributed over a thick zone in relatively uniform material; (4) by deep-seated bending, folding, and plastic flow of rocks on slopes; (5) by incremental movements along a dipping rough-surfaced plane; and (6) by bulging, spreading, and fracturing of steep-sided ridges in mountainous areas. There may be still other types of creep that have not yet been recognized.

Some of these different types of gravitational creep occur in the United States in the Allegheny Plateau region, in Utah, in Yellowstone National Park, in northern New York State, in California, in the Olympic Mountains of Washington, in Alaska, and in the Rocky Mountains of Colorado.

Research in rock mechanics

Strain data obtained in laboratory and field experiments by T. C. Nichols, Jr., and F. T. Lee (USGS) and J. F. Abel (Colorado School of Mines) indicated that large amounts of energy can be concentrated and stored within rock masses and that such energy is available for release. Strains resulting from energy release were measured on surfaces of individual rock specimens cut under conditions that isolated the specimen from strain-inducing confining pressure or temperature conditions. The igneous rock specimens tested released strain energies that measured more than 1×10^3 ergs/cm^3 and, in some specimens, as much as 1×10^6 ergs/cm^3. These strains, measured on the specimen surfaces, were produced from internal energy and were dependent on the original size and shape of the rock. The strain was released both as instantaneous energy and as energy released over a longer period of time. The amount of energy measured was similar to those amounts, previously estimated by other investigators, that were released during rock bursts in similar rocks. Therefore, the present investigators suggest that surface and underground burst failures in large part are due to internal energy released by natural or manmade changes in the geometry of rock masses. The determination of internally stored energy may be critical for the design of mining operations, either above or below ground.

Release of stored energy in large rock masses might cause rock failures and some moderate-sized earthquakes.

Coal mine subsidence studies conducted in the Somerset coal mining district of Colorado during the past 2 yr by C. R. Dunrud revealed that the stresses produced by subsidence in moderately deep to deep overburden above room-and-pillar mine workings control, in a significant way, stress levels in the mine workings as well as disruption of the ground surface. Analyses of subsidence measurements and deformational features mapped at the surface and within the mine workings show that the processes of subsidence comprise two different stress and yield conditions in response to the excavation of mine workings. First, arcuate zones of compressive stress, called compression arches, tend to develop above and below the mine workings and to transfer the overburden load to adjacent solid coal or barrier pillars. Second, the strata within these arches tend to cave and flex downward or heave upward and increase the stresses in the mining area again and reduce them on adjacent barrier pillars or solid coal boundaries.

With time, the compression arches migrate upward into the superjacent strata and downward into the subjacent strata; this movement further increases the stresses in the mining areas and reduces them on the barrier pillars or mine boundaries. The arches may eventually migrate to the ground surface and cause compression fracturing or overthrusting. This activity is commonly followed by local tension

fracturing and further compression failure as a result of the downward flexing of strata into the mine workings. This fracturing can threaten other valuable deposits in the overburden, the surface environment, or the works of man. The rate of migration of the compression arches, and consequently the rate of stress transfer or time before the ground surface is affected, is controlled by the thickness of the overburden, the strength of the overburden and the strata below the mine workings, the rate and sequence of mining, and mine geometry. Mine safety and coal production could therefore be increased if the geologic and engineering factors affecting subsidence were better known. Companies mining the coal stand to benefit from subsidence research as much as those concerned with protecting the environment.

Research in soils engineering

Work on the engineering characteristics of hillside materials in the San Francisco Bay region by C. M. Wentworth, S. D. Ellen, and others yielded new promise for an old test for swelling clays. Numerous methods are used by civil engineers to evaluate the expansiveness of soils and clayey rocks, but most are too expensive for reconnaissance work, and simpler tests either have not been effectively correlated with field performance or have been considered too crude.

However, extensive reconnaissance fieldwork and simple and inexpensive measurements of the free swell (Krynine and Judd, 1966, p. 144) of hundreds of samples indicate (1) that a wide range of free swell values is obtained from various geologic units in the bay region (<20 to 200 percent swell) and (2) that material shown by field evidence to shrink or to become sticky or tough when wet to moist yields free swell values above a threshold of about 50 percent. Careful testing in a commercial laboratory of 25 samples representing the range of free swell values encountered demonstrates that free swell values correlate well with loaded swell values (which are accepted by civil engineers).

Reconnaissance field observations and the simple free swell test thus can be used as an indication of the likelihood that material is expansive (of sufficient swell potential to damage roads, slabs, or light structures) and may be a useful guide to the magnitude of swell potential as well.

Engineering-geologic reports used by government and nongovernment agencies

During the past year, 13 Veterans Administration hospital sites were evaluated geologically by T. C. Nichols, Jr., as a continuation of an evaluation program begun after the 1971 San Fernando, Calif., earthquake. Eleven of these sites were examined briefly in the field. Administrative reports for all sites were transmitted to the Veterans Administration; the potential geologic and earthquake hazards that might affect the future safety of the hospital buildings and patients were delineated.

USGS geologic maps and reports on the geology and water resources of the Anchorage, Alaska, area, such as the one by Chester Zenone, H. R. Schmoll, and Ernest Dobrovolny (1974), have been used by the Planning Department of the Greater Anchorage Area Borough in a variety of ways, ranging from subdivision review and analysis to the preparation of a comprehensive plan for the development of the entire borough. A subdivision ordinance on hillside development requires in-depth review of the effects of topography, geology, hydrology, and engineering where the terrain has slopes in excess of 25 percent. On more gently sloping ground, subdivision development conforms to geologic and hydrologic constraints. The comprehensive plan provides guidelines for certain long-range projections of community needs, including (1) development of additional water-supply facilities; such as damsite locations, and reservation of land for artificial ground-water recharge; (2) location of sites for waste disposal; and (3) selection of open-space areas.

A request for the release of results of testing of physical properties of soils and rocks was received from Purdue University's National Rock Information Center. Data obtained from such testing in the Engineering Geology Laboratory under the direction of R. A. Farrow were entered into a file coded on magnetic tape. A copy of this tape, a description of the coding scheme, and results of the testing were released to the public through the National Technical Information Service (Farrow and Chleborad, 1974).

STUDIES RELATED TO LAND USE AND ENVIRONMENT

Earth-science studies oriented to land use and environment resulted in a broad spectrum of reports and maps that discuss and depict geologic hazards, influences of geologic conditions on man's utilization of the environment, and basic data for land-use decisionmakers.

URBAN GEOLOGIC STUDIES

Tunneling conditions for 34 urban areas surveyed

In studies of 34 urban areas, E. M. Cushing and R. M. Barker found that the most common ground condition was one of hard bedrock underlying less consolidated materials at depths of less than 80 m and that bedrock at depths of 15 m or less was the prevailing condition in 21 areas. Of the areas studied, soft-ground tunneling conditions to depths of more than 80 m occur only at Houston, Memphis, and New Orleans. Ground water is everywhere close to the land surface in the Fort Lauderdale, Miami, and New Orleans areas. In most other urban areas, ground-water conditions are complex, and both water-table and artesian conditions exist within 80 m of the land surface.

"Special features" that would affect construction and maintenance of tunnels include flood-prone areas, buried alluvium-field stream channels, solution cavities, active faults, and deeply weathered bedrock. Each American urban area differs geologically and hydrologically from all others; only the Dallas-Fort Worth and Fort Lauderdale-Miami areas are similar in any considerable way.

This information was compiled from existing sources during a study funded by the U.S. Department of Transportation and is included in an administrative report submitted to that agency.

Land-use information needs being met in Colorado Front Range urban corridor

Studies along the Front Range urban corridor of Colorado, centered on Denver, proceeded down several avenues of land use, urban mineral resources, and urban hydrology. Enactment of land-use legislation by the Colorado legislature in 1974 and a growing environmental awareness on the part of the public have resulted in a large demand for products of the urban study. A map showing mined areas in the Boulder-Weld coalfield by R. B. Colton and R. L. Lowrie was quickly sold out and was reprinted to meet the continuing demand. Maps showing gravel resources by Colton, D. E. Trimble, and H. R. Fitch have been popular with community leaders and land developers as well as with gravel operators. Maps recently released by J. F. McCain and W. R. Hotchkiss show flood-prone areas and are expected to have widespread and immediate applications for a wide spectrum of users. Maps showing the kinds and sites of hydrologic data by E. R. Hampton and the location and quality of water in lakes by T. W. Danielson in the greater Denver area will aid water-resource and land-use planners and managers.

Mountain soils mapping in Front Range urban corridor

The suitability of mountain areas along the Colorado Front Range as sites for the works of man depends partly on the thickness and engineering properties of the soil. K. L. Pierce and P. W. Schmidt studied the distribution, thickness, and character of mountain soils (including saprolite and transported alluvium-colluvium) as they relate to urbanization. Drafts of seven quadrangle maps at a 1:24,000 scale were enthusiastically received by planners. Studies continued in other quadrangles.

Maps are prepared on the basis of geologic reconnaissance, water-well logs, airphoto interpretation, refraction seismology, and regional geomorphic relationships. Map units are selected on the basis of their potential usefulness to planners, developers, and land owners. They consist of five simple soil terrane units: mostly soil, soil with subordinate rock, rock with subordinate soil, mostly rock, and alluvium. Each unit within a given area is defined by the ratio of soil or weathered rock to hard bedrock. Alluvium is used as a separate mapping unit because of its distinctive lithology.

Liquefaction map put to use in San Francisco Bay area

A preliminary map of the liquefaction potential of unconsolidated sediments prepared for the southern part of the San Francisco Bay region has been widely used in the preparation of environmental impact reports and city and county seismic safety elements. Seismic safety elements describe seismic and geologic hazards that may affect a given community and establish goals and policies for dealing with these hazards.

The map was prepared by T. L. Youd, D. R. Nichols, E. J. Helley, and K. R. Lajoie. Map zones are established on the basis of detailed geologic mapping. Liquefaction potential for each zone is estimated from an analysis of lithologic, water-table, and standard penetration test data. Sediments found to have the highest potential for liquefaction are clean granular deposits (Holocene in age) that lie within the younger bay sediments and within flood-plain deposits. Other Holocene deposits generally have moderately low potential for liquefaction. Pleistocene deposits in the region have a generally low liquefaction potential.

ENVIRONMENTAL GEOLOGY OF CITIES AND COUNTIES

Thickness of overburden in Fairfax County, Virginia

Preliminary analysis of the thickness of the overburden in Fairfax County by A. J. Froelich and A. E. Nelson based on water-well and construction data and field studies indicates that residuum on Triassic sedimentary rocks in the western part of the county rarely exceeds 6 m; saprolite on Piedmont crystalline rock in the central upland part of the county locally exceeds 50 m; unconsolidated Coastal Plain and younger upland deposits in the eastern part of the county form an eastward-thickening prism more than 100 m thick. Fresh bedrock is commonly exposed along stream valleys in the Triassic and Piedmont crystalline areas and locally crops out through upland surfaces underlain by quartz bodies and ultramafic and mafic rocks. Each type of overburden has radically different physical, chemical, and mineralogical properties that strongly influence land-use and development capabilities.

Computer mapping for environmental planning

A computer mapping system using cell-formatted storage, analysis, and display has been used to combine existing geologic, hydrologic, and other physical information for environmental analyses of Montgomery County, Md. Working with county environmental planners, J. N. Van Driel produced computer-composite maps showing the occurrence and distribution of shallow bedrock, unstable surface materials, steep slopes, surface water, mature trees, and other factors considered by planners to be limitations to various types of urban development. These composite maps have been received enthusiastically by the county and are being used as the basis for drafting area development plans and also as a standard for determining the environmental consequences of established plans.

Geology-related problems at Memphis, Tennessee

W. S. Parks (USGS) and R. W. Lounsbury (Memphis State Univ.) found that urbanization and industrialization of the Memphis area commonly result in geology-related problems. These problems are associated with foundation materials, aggregate supplies, flood hazard, water supply, solid waste disposal, and earthquake risk. Consideration of these topics as parts of an overall problem in environmental management provides an insight into their close interrelations and points out the need for coordinated studies of the geology and hydrology of the area.

Earth materials in Memphis are suitable for the foundations of residences and light buildings in most places. Site investigations are necessary to determine the bearing capacities of the materials for heavy construction and high-rise buildings. Aggregate supplies are abundant in the immediate vicinity of Memphis and in outlying areas. Nevertheless, the high cost of land and zoning restrictions could become significant factors in their continued development and use. Flood hazard is an immediate local problem where fills and excavations are rapidly constricting or altering the natural flood plain of small creeks and rivers. Both ground- and surface-water resources are abundant, but contamination by leakage and land subsidence could result from continued increases in annual withdrawals from the major aquifer. Earthquake risk was proven to exist in the Mississippi River valley by the New Madrid earthquakes in 1811 and 1812 and by the large number of shocks that have occurred since. Knowledge of the expected magnitudes, frequencies, and destructive effects of earthquakes in the Memphis area is at best rudimentary. Some information is now being collected with seismographs at Memphis and in the immediate vicinity.

Landslides and other disturbed ground in Allegheny County, Pennsylvania

Forty-three maps at 1:24,000 scale prepared by J. S. Pomeroy and W. E. Davies in cooperation with the Appalachian Regional Commission include the 1,890 km^2 of Allegheny County and show landslides, mine-related features (strip mines, dumps, subsidence evidence), cuts, fills, excavations, and recent land modifications for housing and other development. Over 2,200 prehistoric and approximately 800 recent (historic and active) landslide deposits are located, and the maps also show the outlines of the zones considered most susceptible to slope failure on the basis of landslide incidence, rock and soil materials, topography, and other parameters. About 83 percent of Allegheny County's recent landslides occurred in soils and weathered rock derived from the 180- to 200-m-thick Conemaugh Group, the highest percentage of slope failure taking place in the upper half of the unit.

The maps are expected to be used as the areal basis for preparation of model zoning ordinances or for other land-use management guidance by the Allegheny County Department of Planning and Develop-

ment. This department has figures showing that landslide damages in the county may average $2,000,000 a year.

COASTAL ENVIRONMENTAL GEOLOGY

San Mateo County, California

Old topographic maps (1851–66), subdivision maps (1906–10), aerial photographs (1926–41), and historical ground photos (1900?–50) provided the basis for establishing historic sea-cliff erosion rates in San Mateo County. Erosion rates are plotted with lithologic and physiographic data on planimetric profiles of the coastline in an attempt to determine factors controlling coastal erosion. Preliminary conclusions are as follows:

1. The most rapid historic cliff erosion (~0.3 m/yr) occurs where the wave-cut platform of the lowest emergent marine terrace (usually Sangamon) lies at present sea level and wave erosion is merely stripping unconsolidated marine deposits from these old surfaces.
2. The least historic erosion (virtually nil) is along segments of the coast composed of granodiorite at Montara Mountain and the highly indurated Pigeon Point Formation (Upper Cretaceous).
3. Segments of coastline composed of unconsolidated marine terrace deposits (usually Sangamon) generally have low to moderate historic erosion rates (0.1 to 0.2 m/yr) owing to dynamic coastal equilibrium (controlled by headland geometry and wave patterns) but have extremely high erosion potential if this tenuous equilibrium is disturbed (as it was at Half Moon Bay, where erosion rates increased to as much as 2.0 m/yr just south of a breakwater built in 1959).
4. Sea-cliff retreat does not proceed in a steady, continuous manner but rather proceeds intermittently, most material being removed catastrophically during heavy storms or during the winter months when the waves are highest.
5. Landsliding (rotational slumps, debris slides, and block falls) is a dominant coastal process, especially where active faults intersect the coastline.
6. Marine caves are common along segments of coastline consisting of the highly jointed Purisima Formation (Pliocene).
7. The San Mateo County coastline is a sand-deficient coastal regime with sandy beaches providing protection to backshore features only in coves and embayments, across the mouths of drowned valleys, and along the northern sides of headlands (such as Point Año Nuevo) where sand has collected due to southward littoral drift.
8. No data currently are available on the relative proportions of beach sand supplied by direct coastal erosion or stream transport, but stream transport appears to be the dominant agent.

The data gathered in this study have been incorporated into land-use policy by the Central Coast Regional Commission of the California Coastal Zone Conservation Commission and have been used by other Federal, State, and local agencies for numerous land-use problems in the San Mateo County coastal zone. This local study is intended to serve as a prototype for future regional studies of coastal processes.

San Francisco Bay region

The report on coastal geologic processes being prepared as part of the USGS-HUD San Francisco Bay Region Environmental Study served as a prototype for making Earth-science data available to the Central Coast Regional Commission of the California Coastal Zone Conservation Commission. Data compiled by P. A. McCrory, J. C. Tinsley III, H. G. Greene, and K. R. Lajoie on coastal morphology, lithology, and sea-cliff erosion rates provided the basis for establishing three relative coastal stability categories in San Mateo, Santa Cruz, and Monterey Counties. Segments of the coastline characterized by inherently unstable materials such as landslide deposits or sand dunes and by historic sea-cliff erosion rates in excess of 0.3 m/yr were labeled unstable. Segments characterized by inherently stable material such as granite and by historic sea-cliff erosion rates less than 0.1 m/yr were labeled stable. Segments where historic sea-cliff erosion rates fell between these values, or where data were not adequate to establish a precise rate, were labeled moderately stable. The Central Coast Regional Commission adopted land-use policies based on the particular geologic constraints within these three stability categories. These local policies in turn served as the model for statewide policies adopted by the State Commission relating geologic factors and land use along the coastal bluffs.

Data on other geologic features and processes in this segment of the coastal zone are being compiled by Greene, McCrory, and Lajoie in cooperation with the Central Coast Regional Commission. Seismic haz-

ard data are being compiled at a 1:200,000 scale for regional planning purposes. Slope stability data are being compiled at a 1:62,500 scale. Location and original extent of various coastal environments such as beaches, dune fields, and estuaries are being compiled at 1:200,000 and 1:62,500 scales. All this information is used by the Coastal Commission in general planning and in evaluating development proposals and environmental impact reports.

VOLCANO HAZARDS

Increased hydrothermal activity at Mount Baker, Washington

An increase in the emission of steam was first noted March 10, 1975, in Sherman Crater at Mount Baker, and unusually voluminous fumarolic activity was still continuing in late April, according to D. R. Crandell (USGS). The crater is breached on the eastern side and drains into a hydroelectric power reservoir in the Baker River valley. Studies by J. H. Hyde (Univ. of Washington) indicated that many large mudflows of hydrothermally altered rock have originated at the volcano in postglacial time and have moved into the Baker River valley. The possible consequences of another mudflow, as well as the possibility of a pyroclastic eruption, have led to the initiation of several types of monitoring. Seismographs have been installed by University of Washington geophysicists, and other scientists have examined the composition of fumarolic gases; USGS Water Resources Division personnel have been monitoring pH and the chemistry of the stream that drains the crater. According to Stephen Malone (Univ. of Washington), the seismographs did not record any earthquakes of unequivocal volcanic origin during their first few weeks of operation. The U.S. Forest Service is considering placing restrictions on certain kinds of future visitor use in the area of the volcano. David Frank (Univ. of Washington) is compiling and synthesizing all data pertinent to the current activity as they become available.

Potential volcanic hazards in northern California

Hot pyroclastic flows and lahars of volcanic rock debris from two eruptive centers repeatedly spread across the area between the communities of Weed and Mount Shasta, Calif., during Holocene time. Studies of the resulting deposits by C. D. Miller and D. R. Crandell showed that pyroclastic flows and lahars of nonvesicular rock debris moved westward from Shastina, a parasitic cone on Mount Shasta Volcano, about 9,200 yr ago. Similar events recurred between 9,200 and 5,000 yr ago during the formation of the Black Butte plug dome, which is situated 11 km southwest of Shastina. Pyroclastic flow deposits of nonvesicular rock debris and pumice formed at that time extend from north of Black Butte southward beyond Mount Shasta City. Evidence of as much as 10 m of vertical displacement along east-trending faults during the interval between two of the youngest pyroclastic flows from Black Butte suggests that the adjacent area subsided during a late stage of formation of the plug dome. The eruption of new plugs or domes on the western or southern sides of Mount Shasta could result in hot pyroclastic flows and lahars that might endanger life and property in communities near the flanks of the volcano.

Volcano hazards at Lassen Volcanic National Park

Owing to geologic hazards in the Chaos Crags area on the northern side of Lassen Peak, the National Park Service recently closed the Manzanita Lake visitor facilities in Lassen Volcanic National Park. However, Lassen Park remains open. Lassen Peak, the only volcano in the conterminous United States that has erupted in this century, dominates the 427-km^2 park. A period of activity took place between 1914 and 1921. The activity appears to have ceased, and today Lassen Peak is believed to be a dormant volcano. Other features of the park are fumaroles, hot springs, and geysers.

The decision to close the visitor facilities was based on USGS studies made by D. R. Crandell, D. R. Mullineaux, R. S. Sigafoos, and Meyer Rubin. After studying the area, the USGS scientists concluded that rock avalanches could occur without warning in the highly unstable Chaos Crags area east of Manzanita Lake. In a recent news release from the National Park Service, the situation at Manzanita Lake was likened to an event that occurred at Hebgen Lake in Gallatin National Forest near Yellowstone National Park in 1959, where 28 persons lost their lives in an earthquake-caused landslide that destroyed a Forest Service campground.

ENVIRONMENTAL PROBLEMS RESULTING FROM MINING

Surface subsidence over bituminous coal mines, southwestern Pennsylvania

Kent Bushnell compared overburden, mining, and other bituminous coal mining factors with the distribution of recorded damaging surface subsidence events related to the mining of the Pittsburgh and

Upper Freeport coal beds. His findings suggest that the time of mining (before or after April 27, 1966) is more critical to the potential for future damaging subsidence than other factors. April 27, 1966, was the effective date of the Pennsylvania law requiring that coal be left in the ground to support certain structures and to make the opportunity for similar protection available to others. The thickness of overburden above mined-out areas also is a significant factor. Areas with certain overburden thicknesses that were undermined before 1966 have a greater likelihood of future damaging subsidence than areas mined after 1966 or mineable in the future. Damaging subsidence has been known to take place more than 30 yr after cessation of mining. Bushnell's results are contained on a 1:125,000-scale map that is a general classification of land relative to subsidence potential.

Surface-mine reclamation in the eastern Powder River Basin, Wyoming

Reclamation of surface-mined lands traditionally has been considered in terms of reestablishing soils and vegetation on abandoned spoils. However, in large areas of the Powder River Basin of northeastern Wyoming and southeastern Montana, strippable coal deposits are thick in comparison with overburden. The changes in topography, erosion patterns, and surface- and ground-water systems resulting from coal extraction likewise are of critical importance in evaluating reclamation potential. In the Gillette areas along the eastern side of the basin, for example, surface mining of the Wyodak-Anderson coal bed will lower the ground surface 15 m or more in many places as well as create a narrow linear trough as much as 30 m deep at the high wall. Maps now in preparation, showing how the landscape may appear after mining and backfilling and based on present topography and coal and overburden thicknesses, indicate where special planning is required in the premining stages in order to minimize permanent environmental damages and to determine proper reclamation practices.

INVESTIGATIONS RELATED TO NUCLEAR ENERGY

UNDERGROUND NUCLEAR EXPLOSIONS

The USGS, through interagency agreements with ERDA and DOD, investigates the geologic and hydrologic environments of each site where underground nuclear explosions are conducted. Most of these sites are at the Nevada Test Site (NTS). Geologic and hydrologic data are needed to evaluate the safety, engineering feasibility, and environmental effects of nuclear explosions.

Hydrologic studies at and near the NTS have revealed several noteworthy observations in relation to the nuclear testing program.

W. W. Dudley and G. C. Doty completed a water-table map of Yucca Flat that incorporates corrections for the effect of head losses at various depths on composite water levels in observation wells that penetrate the aquifer.

Detailed hydraulic testing by D. I. Leap of the carbonate aquifer at an experimental tracer site in the Amargosa Desert (southwest of the NTS) revealed that the greatest transmissivity is subparallel to the strike of thrust and Basin and Range normal faults. Amplitudes and wavelengths of water-level oscillations are directly related to the size of solution-enlarged fractures within the carbonate aquifer.

Water moving downward through fractures in Rainier Mesa at the NTS was shown by H. C. Claassen to retain a high percentage of bivalent cations, whereas water perched in ash-fall tuffs changes to predominantly monovalent cations.

Analyses by A. F. White of ground water from Oasis Valley (west of the NTS near Beatty) showed that solute compositions are determined principally by hydrolysis and dissolution of volcanic glass in the varied lithologic sequence of the Pahute Mesa (northwestern part of the NTS) ground-water basin. Increased concentration of the solutes within the valley indicates that about half of the ground-water replenishment is consumed from the ground-water reservoir by evapotranspiration.

Hydrologic conditions at Project Faultless, a nuclear explosion conducted off the NTS in northern Nye County, Nev., on January 19, 1968, have been continuously monitored since that date. Water-level measurements in a drill hole that penetrates the collapse chimney above the explosion show that the water level in the chimney had remained stable at about 518 m below the local water level until it began to rise in October 1974. According to G. A. Dinwiddie and D. D. Gonzalez, the water level in the chimney has risen at the rate of 0.3 m/d during October, November, and December of 1974. Radiochemical analyses show a decrease in tritium in the water, presumably because of dilution. The rate of chimney infill is being continuously monitored, and water samples are being collected at bi-

monthly intervals in order to effectively document the change of hydrologic conditions that began in October 1974.

Permanent offsets in ground-water levels, measured with respect to preexplosion water levels, occurred as a result of the Rio Blanco nuclear explosion of May 17, 1973, in the Piceance Creek basin in Colorado. The offsets are as much as −5.2 m in the upper aquifer, +1.5 m in the lower aquifer, and 0.15 m in the Douglas aquifer. According to J. E. Weir, Jr., and Gonzalez, these offsets probably are the result of changes in the effective porosity of the respective aquifers and were observed as far as 29 km from ground zero. Analyses of hydrographs of wells in the vicinity of the Rio Blanco site imply an associated increase in permeability in some parts of the basin, the result being more effective recharge from snowmelt.

Hydraulic fracturing of the gas-bearing formation at the Rio Blanco site conducted in October 1974 did not produce any observable effects on ground-water levels measured in the same wells measured during the Rio Blanco nuclear explosion.

On Amchitka Island in Alaska, W. C. Ballance, Gonzalez, and William Thordarson collected water samples from streams and lakes near the site of the Cannikin nuclear explosion. These samples were analyzed for tritium, gross alpha, and gross beta/gamma content. No appreciable differences were found between these data and the data obtained from water samples collected prior to the Cannikin event.

Investigations into the geomechanical characteristics of the geologic medium are used in site evaluation and development at the NTS. These investigations, conducted primarily in the tunnels under Rainier Mesa, have spawned the development of new instrumentation and techniques, as well as studies to evaluate and improve existing technology.

An air-injection technique to study fracturing around a tunnel in volcanic rocks was developed by C. H. Miller, D. R. Cunningham, and M. J. Cunningham. The method uses a permeameter apparatus to indicate the intensity and depth of natural, stress-induced, and blast-induced fractures around underground openings. Although to date this technique has been used only in the volcanic tuffs of Rainier Mesa, it can be applied in other rock types where permeability is confined to fractures.

The evaluation of in-place rock stress in Rainier Mesa has taken on increased importance in the last few days. Rock stress information is used in the engineering design of underground excavations and in the containment evaluation for underground nuclear explosions. USGS efforts are directed toward the determination of in-place stress and the examination and evaluation of various stress determination methods.

The primary method of stress determination in Rainier Mesa is the U.S. Bureau of Mines overcore technique. This method has been well developed and is considered to give reliable results. Stress determinations made by this method are used as the standard against which the stress determinations of other methods are compared.

Miller and G. R. Terry experimented with the hydrofracture method of stress determination in the tunnels of Rainier Mesa. Several fracturing experiments using colored water were conducted in horizontal and vertical holes. Some of the holes were then mined out, and the induced fractures examined and mapped. Whenever possible, the hydrofracture stress measurements were compared with stress measurements obtained by the overcore method. In some cases, stress measurements obtained by the hydrofracture method provided good data, whereas, in other instances, the results were questionable. Work is continuing, with emphasis on improving hydrofracture techniques and equipment.

R. D. Carroll and M. J. Cunningham made extensive crosshole, uphole, refraction seismic, and sonic velocity measurements in the tuffs on Rainier Mesa. These measurements revealed a horizontal velocity anisotropy of nearly 2:1; the direction of lower velocity is at right angles to the direction of faulting in the area.

RELATION OF RADIOACTIVE WASTES TO THE HYDROLOGIC ENVIRONMENT

Development of nuclear-energy facilities has resulted in nuclear wastes in gases, liquids, and solids. These wastes must be isolated from the hydrologic environment for varying periods of time, depending upon the radioactive half-life of the waste products. USGS research, sponsored by ERDA, has been directed toward methods of disposing of these waste products and understanding geohydrological processes and principles of waste movement from storage and disposal sites.

Mobility of buried radioactive wastes

A study was made to evaluate the geohydrologic and geochemical controls on the possible subsurface migration of radionuclides from a radioactive solid-

waste burial ground. The Idaho National Engineering Laboratory burial ground is located in eastern Idaho above the Snake River Plain aquifer. The subsurface strata are basalt and interbedded sediments. According to J. T. Barraclough, J. B. Robertson, and V. J. Janzer, some waste products have apparently been carried by percolating precipitation and runoff water from the surface burial sites to a sediment bed about 34 m deep. However, owing to statistical error and some possibilities of sample contamination, conclusive proof of the apparent migration is lacking. Therefore, additional subsurface sampling appears to be warranted.

Numerical model of subsurface nuclear-waste percolation

A quasi-three-dimensional numerical model was developed by J. B. Robertson to simulate the migration of aqueous radioactive wastes from disposal seepage ponds at the Idaho National Engineering Laboratory. In the model, finite-difference techniques are used to solve equations of water flow and solute transport for a perched ground-water system with vertical leakage through the bottom. The model adequately simulates observed field data from the real field system and will be used to help analyze present and future subsurface distribution of waste isotopes such as ^{90}Sr. The system incorporates horizontal and vertical flow, nonhomogeneous media, effects of radioactive decay, ion exchange, and hydraulic dispersion. The model indicates that no detectable concentration of ^{90}Sr will percolate into the Snake River Plain aquifer, 137 m below the ponds, within the next 25 yr.

Burial-ground monitoring at Oak Ridge National Laboratory

Solid wastes contaminated by radioactive substances are usually buried to remove the potentially hazardous materials from man's environment. Although contaminants may be leached from the waste, burials are made on the assumption that leached nuclides will be retained in the geologic environment by sorption or ion exchange and thus restrained from pathways leading back to man.

At Oak Ridge National Laboratory in Tennessee, an estimated 170,000 m^3 of waste have been interred in six burial grounds. D. A. Webster reported that the monitoring system is adequate for quantifying contaminants contained in surface water released to the Clinch River but is inadequate for defining contaminant origin and for monitoring the transport of contaminants in ground water from the burial grounds to the surface drainage.

Disposal of radioactive wastes in shale

Low- and intermediate-level liquid radioactive wastes (specific activity less than 0.53 Ci/l) were mixed with cement and clay and injected by hydraulic fracturing into a dense, nearly impervious shale formation with nearly horizontal bedding. The injected wastes were thereby immobilized and contained within a thin zone of the shale, where they were isolated from the biosphere. This technique was used to ascertain whether bedding-plane fractures can be induced hydraulically in shale and whether the orientation of the induced fractures can be determined by a reliable and economical method.

Results of research projects conducted at West Valley, N.Y., and Oak Ridge, Tenn., proved that bedding-plane fractures can be induced and propagated hydraulically in shale, at least at a shallow depth (600 m). R. J. Sun (1969) developed a mathematical model to describe the relationship between the uplift of the ground surface and the induced horizontal fractures. Sun (1973; Sun and C. E. Mongan, 1974) demonstrated that the orientation of induced fractures can be predicted by injection pressure and pressure decay. The predicted results can be verified by gamma-ray surveys made in observation wells located within a radial distance of 60 to 100 m from the injection well if the injected fluid is tagged with gamma-activity isotopes.

A hydraulic fracturing site for disposal of radioactive wastes at the Holifield National Laboratory (formerly the Oak Ridge National Laboratory) was evaluated by the methods developed during the research projects.

Borehole gamma spectrometry used to locate radioisotopes

T. A. Taylor and W. S. Keys, using borehole gamma spectrometry, were able to locate and identify artificial radioisotopes in a cased well adjacent to the Maxey Flats radioactive-waste burial ground in Kentucky. The investigators were able to identify ^{60}Co, ^{134}Ce, and ^{137}Ce behind the casing in test hole 12E. By using energy discrimination through threshold detectors, they were able to make a continuous gamma log that responded mainly to the two cesium isotopes and to make another gamma log that responded mainly to ^{60}Co.

Two spectral probes (with outside diameters of 4.76 and 10.16 cm) have been developed and successfully tested; their present depth limitation of 1,800 m and temperature limitation of approximately 65°C can be extended by modifications of the probes.

Waste management, Paradox Basin, Utah

The salt-bearing Middle Pennsylvanian Paradox Member of the Hermosa Formation is diapiric in nature and has a thickness of at least 3,400 m in the core of the northwestern end of the Salt Valley anticline in Grand County, Utah, according to R. J. Hite and S. W. Lohman (1973). The Paradox is characterized by a sequence of salt units alternating with units of anhydrite, dolomite, and black shale. Because the Paradox beds have flowed from adjacent synclines into the anticline, the internal structure of the salt-bearing rocks is complex. In the collapsed and breached axis of the anticline, the top of the salt rises to within 200 to 250 m of the surface beneath a caprock of insoluble residuum that has resulted from the removal of salt by solution.

Results of field studies by L. M. Gard, Jr., and R. P. Snyder showed that the oldest post-Pennsylvanian rocks exposed in blocks foundered in the caprock are the upper part of the Brushy Basin Shale Member of the Jurassic Morrison Formation overlain by the Burro Canyon Formation, the Dakota Sandstone, and the Mancos Shale of Cretaceous age. These foundered blocks of Mesozoic rocks are folded and faulted far less intensely than the contorted sandstone, limestone, and shale beds of the Paradox Member.

Waste emplacement in bedded salt

C. L. Jones, L. M. Gard, Jr., A. L. Brokaw, and G. O. Bachman completed field studies to determine the geologic and hydrologic conditions in a part of southeastern New Mexico that is being considered as a possible site for emplacement of nuclear wastes in the bedded salt of the Salado Formation. Two exploratory boreholes (923 and 1,194 m deep) were drilled to investigate the hydrogeologic framework and obtain samples for mineralogical, chemical, and other studies. Hydraulic tests indicated that the rocks above the Salado are not saturated with ground water and have a very low transmissivity. Other factors favorable to the area include (1) very high geologic stability ranging over 225×10^6 yr, (2) probable protection from exhumation by erosion and from invasion by meteoric ground water for several hundred thousand years, and (3) availability of remote public lands with thick (>500 m) salt deposits.

SITES FOR NUCLEAR-POWER REACTORS AND OTHER FACILITIES

Reactor-site investigations

Twenty-two reactor sites in various states and Puerto Rico were reviewed and evaluated at the request of the Nuclear Regulatory Commission (formerly the Atomic Energy Commission) during the past year by R. H. Morris and other members of the Reactor Site Investigations Project. The purpose of these investigations was to allow engineering design criteria for nuclear facilities to be chosen on the basis of thorough local and regional geologic data collected by an applicant who wishes to build a nuclear-power reactor.

Site seismicity

Seismic evaluations submitted by applicants consider the seismic history of a reactor site and its relation to the tectonic framework of the area. At the request of the Nuclear Regulatory Commission, S. R. Brockman and J. F. Devine reviewed the evaluations of sites in areas of differing seismicity and when necessary appeared as expert witnesses at hearings.

Quaternary dating techniques

Loess stratigraphy in southern Idaho, near the National Reactor Testing Station, shows several buried soils more developed than the surface soil. K. L. Pierce defined four episodes of loess deposition, each followed by a soil-forming interval. Material from a thin volcanic ash in the loess beneath the highest well-developed buried soil has been collected for fission-track dating. Superhydration age estimates by V. C. Steen-McIntyre indicated that the ash is much older than 7,000-yr-old ash and significantly younger than 600,000-yr-old ash; the ash is probably about 100,000 yr old.

FLOODS

Three major phases of USGS flood studies are (1) measurement of stage and discharge, (2) definition of the relation between the magnitude of floods and their frequency of occurrence, and (3) delineation of the extent of inundation of flood plains by specific floods or by floods having specific recurrence intervals.

OUTSTANDING FLOODS

Hydrologic assessment of a flash flood in Eldorado Canyon, Nevada

A devastating flash flood of thundershower origin struck Eldorado Canyon, a 9-km^2 drainage area in southern Nevada, at about 2:30 p.m., September 14, 1974. The flood killed at least 9 people, destroyed 5 trailer homes and damaged many others, obliterated a restaurant, and destroyed 38 vehicles, 19 boat trailers, 23 boats, half of the boat-docking facilities, and the gas dock. The severe runoff resulted from intense basinwide rain and hail at rates of up to 76 mm of precipitation per half hour. The storm moved downbasin and generally increased in intensity with time, this increase compounding the runoff rates. In a report by P. A. Glancy and Lynn Harmsen (1975), peak discharge was estimated to be 2,150 m^3/s just upstream from the developed area near the canyon terminus. Runoff deposited an estimated 53,500 m^3 (about 91,000 metric tonnes) of inorganic sediment in Lake Mohave and throughout the downstream canyon reach. It also delivered an estimated 4,930 m^3 of organic or floating debris to Lake Mohave as well as about 2,500,000 m^3 of water. The inorganic sediment was estimated to consist of less than 1 percent boulders, 40 to 60 percent gravel, 20 to 40 percent sand, and 10 to 25 percent silt clay. The recurrence interval for runoff of this magnitude is great, but a similar event could occur in any given year. Although it is common in the desert Southwest, this type of hydrologic event is not fully understood and is frequently ignored; thus, the danger to developed areas is ever present. With proper understanding and planning, the risk of damage from similar floods in the future may be greatly reduced.

Flooding on St. Croix and St. Thomas, V.I.

Extensive flooding on St. Thomas and St. Croix, V.I., resulted from heavy rains on November 12, 1974; as much as 102 mm of rain fell in a 4-h period. Estimated damage exceeded $1 million on St. Croix and also on St. Thomas. W. J. Haire and K. G. Johnson reported that flood magnitudes approached those of the May 1960 flood. The extent of flooding was delineated on topographic maps (scale 1:4,800); flood profiles were obtained for about 24 km of channel.

FLOOD-FREQUENCY STUDIES

Flood-frequency analyses of California streams

S. E. Rantz and J. R. Crippen (1975) developed a method for estimating the long-term value of the logarithmic skew coefficient for use with the log-Pearson type III distribution in computing the flood-frequency curve for a gaged site. They developed regional equations that relate the logarithmic skew coefficient to logarithmic transformations of (1) mean annual basinwide precipitation and (2) mean annual peak discharge per square kilometre. The technique seems to be satisfactory for use in the greater part of California where, over large areas, the peak discharge in any year is usually associated with a single widespread general storm—or with a series of such storms where snowmelt runoff is involved—rather than with localized precipitation events.

Flood-flow studies in Connecticut

L. A. Weiss analyzed the magnitude and frequency of annual maximum peak streamflows for the period of record at 105 stream-gaging stations and the magnitude and frequency of the annual maximum rainfall for storm durations of 1, 4, 6, 12, and 24 h. Historical data at long-term stream-gaging sites were used to compute skew coefficients; these in turn were used to relate magnitude to frequency. Long-term skew and standard deviation were plotted on isopleth maps and were then used to compute skew and standard deviation at short-term sites. Ratios between long-term mean and short-term mean for long-term sites were applied to short-term sites to make them comparable to the long-term sites.

A regression analysis of the 2- and 100-yr floods for nonurbanized sites was found to be related to parameters such as drainage area, main-channel length divided by the square root of main-channel slope, and rainfall duration and frequency.

The standard error of estimate for nonurbanized streams with drainage areas ranging from 2.6 to 26 km^2 was ±35 percent for the 2-yr flood and ±48 percent for the 100-yr flood. The standard error for streams with drainage areas larger than 26 km^2 was ±27 percent for the 2-yr flood and ±35 percent for the 100-yr flood. For eight urbanized streams in the Connecticut River basin in the State of Connecticut, the ratio of the computed to the actual 2- and 100-yr floods was found to be related to the percentage of the drainage area that is storm sewered. For 100-percent sewering, the ratio of the urbanized to nonurbanized 2-yr flood was 3:1, and for the 100-yr flood it was 2:1.

Flood profiles of the Alafia River in west-central Florida

The Alafia River basin in west-central Florida drains about 109,000 ha of land that is undergoing

rapid urban development. Some residential developments are on the flood plain of the river, which discharges into East Tampa Bay. A. F. Robertson reported that recurrence intervals of seven different floods and flood elevation profiles have been determined for 67 km of the river and its two principal tributaries.

Depth and frequency of floods in Illinois

B. J. Prugh, Jr., developed multiple-regression equations for predicting the 2-, 5-, 10-, 25-, 50-, and 100-yr flood depths from data collected from 177 gaging stations in Illinois. Relationships based on area, slope, and 2- and 100-yr flood discharges were studied. The 2-yr flood discharge was selected as the best variable to predict the various frequencies of flood depths. The final equations had standard errors of estimate that varied from 31 percent for the 2-yr flood depth to 23 percent for the 100-yr flood depth. The equations will be useful for advanced planning and preliminary flood-plain evaluations but are not designed to replace detailed hydrologic studies.

Duration and frequency of high flows on Iowa streams

A report by O. G. Lara (1974), which contains statistical data on flood volumes for 97 recording gaging stations in Iowa, has been published. Data included in tables, are the magnitude and the frequency of occurrence of maximum annual average flows and the corresponding volumes for selected periods ranging from 1 to 183 consecutive days. The tables also include the water-surface elevations corresponding to the listed elevations.

Estimating peak discharges in Massachusetts

G. D. Tasker (C. G. Johnson and Tasker, 1974a) compared a modification of the Potter method (W. D. Potter, 1957) with another multiple-regression technique to predict the 10- and 50-yr peak discharges at 77 gaging stations in Massachusetts. The predicted peak discharges made by each method were compared with the peak discharges estimated from station frequency curves. Results indicate that, although the random error for both methods is about the same, the modified Potter method systematically predicts peaks that are higher (150 percent) than those estimated from station frequency curves.

Flood-frequency studies in Minnesota

A multiple-regression analysis of all gaging-station records in Minnesota is underway to derive equations that will provide flow estimates for various frequencies of floods. L. C. Guetzkow reported that initial analyses of station frequency curves indicate that the results of the log-Pearson type III method are unacceptable. Computation of a log-Pearson distribution using an assigned regional value for the skewness of the logarithms has been adapted to derive data values for the regression analysis that are based on the study of individual gaging-station frequency relations.

Flood-frequency study on small streams in Missouri

L. D. Hauth (1974) reported that the USGS rainfall-runoff model was used in Missouri to provide small-stream peak-flow data in a statewide flood-frequency study. Regional skew coefficients defined by C. H. Hardison (1974) were used in large-drainage-area station frequency curves developed by the log-Pearson type III distribution.

The definition of estimating equations based upon combined large- and small-stream data indicated that the assumption of a linear relation between the logarithms of the variables was inadequate. Alternative curvilinear models and variable transformations were tested, and the most satisfactory model found was in the form $Q=b_1A^{b_2A^{b_3}}S^{b_4}$, where A is the basin size and S is the main-channel slope. Constants in the logarithmic transformation, $\log Q=\log b_1 + b_2A^{b_3}\log A+b_4\log S$, could not be evaluated directly by linear multiple regression; however, repeated trial and error solution indicated that when $b_3=-0.02$, multiple-regression analysis to determine the remaining constants provided relations having the minimum standard error of estimate.

Estimating magnitude and frequency of floods in North Carolina

N. M. Jackson, Jr., conducted a study to develop equations for estimating the magnitude and frequency of floods on ungaged natural streams in North Carolina. The step-backward multiple-regression technique relating flood peaks to basin and climatic characteristics was used. Preliminary results indicate that two sets of equations, one for the Coastal Plain and one for the mountains and the Piedmont province, are necessary.

Small-area flood-frequency study in North Dakota

Flood data from 126 sites have been analyzed by regression analysis to provide relations for estimating the magnitude of floods in small basins in North Dakota. Equations were developed by O. A. Crosby for the 10-, 25-, and 50-yr floods. The State was divided into three regions to improve the estimating relationships. The parameters found significant in defining these relationships were drainage area, stream

density, soil-infiltration index, and evaporation. The standard errors of estimate for the regression equations ranged from −53 to +115 percent. The relations developed can be used for any site in North Dakota in a drainage area ranging from 0.2 to 260 km^2 where the flood flow is unregulated.

Floods from small drainage areas in New Mexico

A. G. Scott (1974) reported that a trial extension of the record of annual flood peaks for one station in New Mexico was made by utilizing a rainfall-runoff hydrograph simulation model. A comparison of the frequency curves of annual peaks for recorded and simulated data indicates that results of the simulation are reasonable.

Flood-frequency relations in Pennsylvania

Regression models relating floods with recurrence intervals of 2.33, 10, 25, 50, and 100 yr to drainage basin characteristics were completed for eight defined flood regions that cover Pennsylvania. H. N. Flippo, Jr., reported standard errors of estimate in the range of 9 to 37 percent for those models applicable to drainage basins larger than 39 km^2. The highest standard error of estimate for those models applicable to drainage areas from 5 to 39 km^2 is 56 percent.

Small-area flood hydrology of Massachusetts and Vermont

C. G. Johnson and G. D. Tasker (1974a, b) developed a technique for estimating the magnitude and frequency of floods on streams in Massachusetts with drainage areas between 0.65 and 1,290 km^2 and on streams in Vermont with drainage areas between 0.70 and 2,700 km^2. Multiple-regression techniques using basin characteristics and data collected at a network of gaging stations defined the relation between flood peaks. Results show that flood peaks can be estimated from knowledge of a basin's drainage area, its average seasonal snowfall, the area of its lakes and ponds, and its maximum 24-h rainfall having a recurrence interval of 2 yr.

FLOOD MAPPING

Flood-hazard study—100-yr flood stage for Apple Valley Dry Lake, California

A study of the flood hydrology of Apple Valley, Calif., was undertaken by M. W. Busby to determine the 100-yr flood stage for Apple Valley Dry Lake. Synthetic hydrologic techniques were used because no adequate hydrologic or meteorologic data for the basin were available. The 100-yr flood-zone stage was estimated to be at an elevation of 886.82 m above mean sea level.

Flood maps of Cypress Creek, Florida

W. R. Murphy, Jr., developed flood profiles of the 2-, 5-, 10-, 25-, 50-, and 100-yr flood-peak discharges for the lower reach of Cypress Creek under existing hydrologic conditions. The study area includes a stream reach that may become a flood-detention area.

Flood-prone areas in Minnesota

L. C. Guetzkow reported that studies are being conducted on designated reaches of streams and isolated communities (Guetzkow, 1971, 1972a, b; G. H. Carlson, 1971a, b, 1972; Guetzkow and Carlson, 1974; K. T. Gunard, 1972; C. W. Saboe, 1973) to provide information required by Minnesota State regulations to implement comprehensive flood-plain management programs for flood-prone areas. Priorities for the selection of study areas are based on the degree of flood-damage potential and development pressures. The reports contain flood-frequency analyses, flood profiles, flood-inundation maps, and floodway evaluations. These data have contributed significantly to making the public aware of potential flood dangers and have provided community officials with the information necessary for adoption of land-use control measures.

Flood-insurance studies in Puerto Rico

Investigations were conducted by W. J. Haire to identify flood-hazard areas and to provide the flood profiles and flood-elevation frequency data that are used to establish the actuarial rate structure for flood insurance. The data are also used to evaluate land-use control measures that local governmental units must adopt to maintain eligibility for Federal flood insurance.

Flood-prone areas in Puerto Rico

Flood discharges on the Río Tallaboa, Río Coamo, Río Utuado, Río Guadiana, and Río Jayuya with recurrence intervals of 50 and 100 yr were determined by regional analyses. W. J. Haire and K. G. Johnson, using step-backwater techniques to define flood profiles, delineated areas subject to flooding. The data are used to evaluate required land-use control measures for local government agencies.

Hypothetical earthquake-caused floods in Jackson Hole, Wyoming

At the request of the National Park Service, the USGS prepared a flood map for the Snake River from Jackson Lake dam to a point 61 km down-

stream. Hypothetical floods were routed downstream for three cases: (1) Instantaneous destruction of the outlet structure, (2) instantaneous destruction of the entire dam, and (3) waves overtopping the dam. Assuming worst case antecedent conditions, W. R. Glass, J. G. Rankl, and T. N. Keefer utilized an accelerated discharge due to the travel of a negative wave through the reservoir and Muskingum storage-routing techniques to develop outflow hydrographs for the first two cases of dam failure. For the case of wave overtopping, a 3-m wave was assumed to be propagated from the upstream end of the reservoir. A multiple-linearization flow-routing model was calibrated with streamflow records and modified to handle supercritical flow. Peak discharge rates calculated as outflow from Jackson Lake were 5,340, 13,740, and 990 m^3/s, respectively, for the three cases; modeled results indicated that these peaks had attenuated 48 km downstream to 5,220 and 12,710 m^3/s for the first two cases. The rate of tributary inflow used in the computation was 330 m^3/s.

Maps of flood-prone areas

Areas inundated by the 100-yr flood are outlined on topographic maps as part of the National Program for Managing Flood Losses. The objective of this program is to quickly inform cities and towns of the general extent of their potential flood problems. About 12,000 such maps have been completed for all of the States, the District of Columbia, and Puerto Rico.

The program has progressed in two phases. The first phase, which began in 1969, was directed toward defining flood limits in populated areas where significant flood problems were known and flood information was urgently needed. The second phase, implemented during 1972, expanded the areal coverage to include areas in which future development was envisioned.

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 year as Hydrologic Investigation Atlases for the following areas: Waiahole-Waikane, Oahu, Hawaii (C. J. Ewart and Reuben Lee, 1975); Saunders to Man, W. Va. (G. S. Runner, 1974); and Ipswich River (L. A. Swallow and D. J. Fogarty, 1974) and Neponset River, Mass. (L. A. Swallow and G. K. Wood, 1974).

WATER QUALITY AND CONTAMINATION

Arsenic and mercury in proposed reservoir environment

R. F. Middelburg, Jr., reported that two toxic trace elements, arsenic and mercury, are known to be present in an area that will form part of a new reservoir, Lake Sonoma, in Sonoma County, Calif. The problem primarily centers around a small tributary, Little Warm Springs Creek, which will be flooded by the proposed reservoir. Located on a 200-m section of the creek are three geothermal hot springs known as Skaggs Springs, numerous geothermal seeps, and an abandoned quicksilver mine.

Arsenic has been detected in the outflow of the springs, and realgar crystals (AsS) can be found in outcrops within the area. Very little mercury has been detected in the waters emanating from the area, but it can be detected in elevated concentrations in sediments and biota.

Asbestos was thought to be a potential hazard, but it has not been detected in any of the water samples. Boron concentration levels may be high enough to affect boron-sensitive plants such as grapes, which are grown extensively in the valley below the proposed reservoir.

Monitoring areal and temporal water-quality variation in the San Lorenzo River basin, California

The San Lorenzo River basin is experiencing rapid urbanization, and, as a result, heavy demands are being made on the water resources and waste-water disposal capabilities of the basin. Water-quality data from previous studies have not been adequate to define baseline conditions or to assess sources of degradation.

In order to determine areal and temporal variations and problem reaches in the basin, a monitoring system of 15 stations was established. The general scheme was to locate one station upstream from a community and one station downstream to assess possible contamination from community septic tanks. Samples were collected monthly.

Although the routine monitoring provided information on monthly and seasonal variations in water quality, shorter period effects were not detectable. Therefore, an intensive diel survey was made.

Preliminary results after 6 mo of sampling indicate similar water quality among stations. Water quality is generally within State standards. No significant diel variations have been noticed. Temporal water-quality degradation corresponds to periods of high flow caused by rainfall runoff.

Contamination of ground water by seleniferous sediments

Water from certain domestic wells in the vicinity of Golden, Colo., contains selenium in concentrations as high as 450 μg/l—45 times the maximum level set by the USPHS for drinking water. The selenium is dissolved from organic-rich Cretaceous sediments of the Arapahoe Formation. R. E. Moran reported that such high selenium concentrations are areally discontinuous in the ground water and are associated with high gross alpha activities (80 to 160 μg/l as natural uranium) and high sulfate (300 to 1,500 mg/l), nitrate (7 to 22 mg/l as nitrogen), and strontium (1,700 to 9,400 μg/l) concentrations.

Saltwater intrusion through corroded well casings

Results of an investigation conducted by D. H. Boggess indicated that saltwater intrusion has occurred in the upper Hawthorn aquifer at several places in the Cape Coral area in Florida. Chloride concentrations in water from the aquifer, which normally range between 100 and 200 mg/l, have increased to a maximum of 9,500 mg/l in one area. The source of the intruding saltwater has been identified as the water-table aquifer, which in some places contains water with chloride concentrations of 27,000 mg/l. The intrusion occurs as a result of corrosion of metal well casings in individual wells, which permits downward leakage of saltwater into the upper Hawthorn aquifer.

Rural runoff

The loads of nitrogen, phosphorus, organic carbon, dissolved solids, pesticides, and trace metals entering a rural canal in southern Florida in runoff were studied by B. G. Waller. Criteria were to be established for the acceptable loads of nitrogen and phosphorus that may enter this canal in runoff from rapidly expanding urban developments. The waters within the canal are backpumped into Conservation Area 3 for storage purposes and drainage of this subbasin. The maintenance of high-quality water within the South New River canal and the adjacent conservation area is dependent on preventing contaminated runoff from entering the canal.

Contaminants in Broward County, Florida, controlled canal system

Quarterly samplings for nutrients and bacteriological parameters and diel studies of dissolved oxygen, pH, and alkalinity in the Broward County controlled canal system showed a slight decrease in contaminants caused by man's activities, according to H. W. Bearden and C. B. Sherwood, Jr. These changes may be the result of local agencies' efforts to reduce the amount of treated sewage effluent entering the canal system.

Coliform contamination of Floridan aquifer well

Analyses of water samples collected from three isolated sections of the Floridan aquifer in north Tampa (Temple Terrace) by J. W. Stewart, C. L. Goetz, and L. R. Mills showed that the upper section (30 to 36 m below land surface) had a higher color reading, more dissolved iron, and a higher concentration of coliform bacteria than the other sections tested. Fecal streptococci were found only in the middle section (37 to 40 m below land surface). The bottom section (40 to 47 m below land surface) had the lowest concentration of iron and coliform bacteria.

Domestic water supplies contaminated in Hillsborough County, Florida

Chemical and biological analyses of water samples collected in an area where a sinkhole occurs in a lake in the southwestern part of Hillsborough County, Fla., indicate that the sinkhole is interconnected with several domestic water-supply wells that are developed in the limestone aquifer. According to A. D. Duerr and C. L. Goetz, living copepods, typical of those in lake-bottom habitats, were recovered from two wells. Color units near the lake sink and two wells were recorded as 225, 120, and 150, respectively; tannin and lignin values were 2.5, 1.8, and 2.0 mg/l, respectively, and total organic carbon was 16, 13, and 14 mg/l, respectively.

Sewage effluent disposal by spray irrigation

Since 1966, the city of Tallahassee, Fla., has been experimentally disposing of up to 5,700 m^3/d of secondary treated sewage effluent by spray irrigation. Effluent has been sprayed on a sandy soil with a variety of crop cover: undisturbed forest, rye, ryegrass, pearl millet, kenaf, sorghum-sudangrass, Argentine behiagrass, and corn. Bedrock is generally 9 to 15 m below land surface. Groundwater levels in the area are generally coincident with bedrock.

In some respects, the quality of the sprayed effluent was improved by filtration through the soil and rock materials. L. J. Slack (1974) reported that BOD was reduced to less than 5 mg/l, fecal coliform bacteria were removed, almost total phosphorus removal was achieved, and from 31- to 100-percent denitrification took place in irrigation fields

that received from 50 to 200 mm of effluent per week.

High-rate effluent application of 350 mm/week onto 7.3 ha of undisturbed forest resulted in increased chloride and nitrogen to depths of at least 82 m and extending laterally about 550 m. Natural chloride and nitrate-nitrogen concentrations in this freshwater aquifer are 2 and 0.05 mg/l, respectively. Chloride and nitrate-nitrogen concentrations ranged from 14 to 51 and from 3.7 to 32 mg/l, respectively, for samples collected from depths of 13 to 82 m at a well downgradient of the heavily sprayed area.

Landfill contaminants in eastern Pinellas County, Florida

Mario Fernandez, Jr., reported that contaminants from a sanitary landfill site in eastern Pinellas County, Fla., are moving away from the site through the shallow sand aquifer. However, preliminary findings at a nearby sludge-disposal operation, which began in November 1974, indicate that leachate from the sprayed sludge is being retained within the disposal area.

Underground disposal of liquid industrial wastes

Since 1963, more than 38 million cubic metres of acidic industrial waste has been injected under high pressure into a confined saline-water-filled limestone aquifer of low transmissivity between 430 and 520 m below land surface near Pensacola, Fla. G. L. Faulkner and C. A. Pascale (1975) reported that, by 1975, injection rates averaged about 145 l/s. Wellhead pressures at the two injection wells averaged 12 kg/cm^2 (1,177 kPa). The pressure at two deep monitor wells in the injection zone 3.1 km north and 2.4 km south of the injection site averaged 7.9 kg/cm^2 (775 kPa). At the injection site, pressure in a shallow monitor well in the aquifer immediately above the 67-m-thick confining layer averaged about 2.1 kg/cm^2 (206 kPa) and continued to decline slightly.

A regional monitoring program revealed that, by mid-1974, the waste body occupied an area of slightly more than 18 km^2 in the upper approximately 15 m of the injection zone. There are no indications that waste has leaked upward through the 67-m-thick confining layer or that pressure increases in the injection zone have had any effect on pressure in the aquifer above the confining layer. By mid-1974, pressure in the injection zone at the injection site had increased eightfold since injection began, and it is calculated that pressure effects in the injection zone extended over an area of more than 13,000 km^2.

Increases in alkalinity and dissolved organic carbon concentration at the southern monitor well, a noticeable increase in gas content, and a distinctive odor of injected waste indicated the arrival of dilute waste at the southern monitor well in mid-1973; organic analyses of the well water also showed that a dilute form of the organic waste had reached the well. The gases methane, nitrogen, carbon dioxide, argon, and helium were detected in both deep monitor wells. The amount of methane in gas samples from the southern monitor well was 1½ times higher (79.5 percent by volume) than that in samples from the northern monitor well.

Sulfate-chloride ratio decrease indicates waste migration

M. I. Kaufman and D. J. McKenzie (1975) found that geochemical data from an industrial deep-well waste injection system southeast of Lake Okeechobee, Fla., indicate a decrease in sulfate concentration concomitant with an increase in hydrogen-sulfide concentration, which is a result of the oxidation of injected organic waste by anaerobic bacteria. Subtle decreases in the sulfate-chloride ratio suggest that the waste migrated upward to a shallow monitor well about 27 mo after waste injection began and again within 15 mo of the resumption of waste injection after the injection well was deepened. The possibility of a hydraulic connection between the injection zone and the overlying monitoring zone is implied. The decrease in the sulfate-chloride ratio appears to be a sensitive indicator of waste migration.

Stream-temperature characteristics

Intermittent water-temperature measurements collected at 147 stream-gaging stations in Georgia were analyzed by T. D. Steele and T. R. Dyar by means of a harmonic curve-fitting technique. Regional analyses of data for most unregulated streams indicate a high degree of correlation of both harmonic mean temperatures and seasonal variation with the latitude of the measurement site. The altitude of a gaging-station site is an important variable for predicting water temperatures in the northern mountainous part of Georgia.

Harmonic analyses of temperature measurements for highly regulated rivers such as the Savannah and the Chattahoochee largely reflect the influence of reservoir releases and thermal powerplants. Time-trend analyses of those sites with relatively long records clearly reflect changes in stream-tem-

perature patterns that were caused by man's activities.

Central Illinois urban-runoff study

Four gaging stations and one precipitation recorder have been established on Sugar Creek and its tributaries in the Bloomington-Normal area to study the water-quality aspects of combined sewer runoff. B. J. Prugh, Jr., reported that water samples are collected at monthly intervals and during storm events in an effort to develop concentration hydrographs for the various parameters being studied. Items such as coliform bacteria, chlorides, suspended solids, nitrogen and phosphorus compounds, organic carbon, pesticides, herbicides, and 10 common metals are being examined along with dissolved oxygen, pH, conductivity, discharge, and rainfall.

Investigation reveals source of mineralized water in southwestern Kansas

Naturally occurring contamination of ground water was identified by E. D. Gutentag, D. H. Lobmeyer, and S. E. Slagle at four sites in Meade and Seward Counties where fresh ground water in unconsolidated deposits of Pleistocene age is hydraulically connected to highly mineralized water in underlying rocks of Permian age. Water-level measurements in observation wells at the sites showed that hydraulic head in the Permian rocks is as much as 3 m higher (adjusted for density) than head in the unconsolidated deposits. This difference in head caused water containing 19,000 to 34,000 mg/l of dissolved solids to move upward into the unconsolidated deposits, which generally contain water with a dissolved-solids content of about 250 mg/l. At the four sites where contamination was identified, water in the unconsolidated deposits contained as much as 2,400 mg/l of dissolved solids.

Graphic computer displays aid water-quality evaluation

Isopleth maps of DO concentration were developed by S. P. Larson, W. B. Mann IV, and T. D. Steele for a 177-km segment of the Mississippi River in the Minneapolis-St. Paul, Minn., metropolitan area. A general-purpose computer contouring program was used to draw isopleths based on periodic monthly sample data collected for 1971–73 at 13 stations. The lowering of DO concentrations downstream of waste-water discharge points is evident during periods of low flow. Dilution during periods of high flow is also clearly evident. In general, the isopleth maps provided a means of concurrent graphic evaluation of the spatial (location along the river) and temporal variations of DO concentration.

Time-series and time-trend analyses of 35 to 47 yr of data at five stations indicated significant changes in some water-quality variables subsequent to construction of the major metropolitan waste-treatment plant in 1938. Diversion of most of the domestic waste load from the river through the combined sewer system for treatment is evidenced by decreased BOD and coliform levels and increased DO concentrations at stations upstream from the treatment plant. Although water at stations downstream from the plant was affected by treatment effluent, changes in water-quality characteristics subsequent to plant construction can be detected by graphic time-series analyses.

Nitrate in the water of a supply well at Hawthorne Naval Ammunition Depot, Nevada

On the basis of hydraulic and chemical data from the supply well at the Hawthorne Naval Ammunition Depot and 17 nearby test wells, A. S. Van Denburgh and F. E. Rush concluded that as much as 20 mg/l of nitrate (as nitrogen) originates in sewage ponds 370 m from the supply well. The percolating sewage effluent is contaminating ground water in the upper alluvial aquifer, which is about 23 m deep. The contaminated ground water has also moved downward from the upper aquifer (principally by leakage through a 152-m supply well during long periods of disuse) to locally contaminate deeper alluvial aquifers.

Effect of sludge disposal on ground-water quality

The controlled land disposal of anaerobic digested sludge is being studied in Ocean County, N.J., to determine several factors, one of which is its effect on the shallow ground-water system. Three different soil-type sites have been subdivided into 12 plots; each plot receives a different application of sludge, consisting of about 5 percent solids, at a rate of from 22 to 90 t ha^{-1} yr^{-1}. William Kam (Kam and J. J. Murphy, 1974) reported that preliminary results indicate that ground-water contamination is greatest under the 90-t/ha plot. During the 575 d since the start of sludge application in June 1973, the nitrate-nitrogen concentration increased from less than 1 mg/l to about 65 mg/l under one of the 90-t/ha plots, 7 mg/l under one of the 45-t/ha plots, and about 9 mg/l under one of the 22-t/ha plots.

Impact of land-use change on water quality

The suburbanization of rural Winslow Crossing (formerly Sicklerville), N.J., has had its greatest impact to date on the area's surface- and ground-water quality. J. J. Murphy reported that sediment loads, carried by storm runoff from land being prepared for home construction, have increased from 4.5 to 450 t/ha. As homes are completed and occupied, the sediment load is gradually diminishing. Conversely, the nutrient, pesticide, and toxic-metal load in the streams and bottom sediments is increasing. Small storm-runoff detention ponds within the developed areas exhibit thin layers of algae on their surfaces during the summer months.

Sewage disposal by means of infiltration ponds has resulted in contamination of the aquifer surrounding the sewage-plant area. Nitrogen content in nearby observation wells has reached 30 mg/l. The shallow water-table aquifer discharges to nearby Fourmile Branch Creek, and the nitrogen loading of this stream is gradually increasing.

Ground-water contamination by landfills

Plumes of leachate-contaminated ground water emanating from two solid-waste landfills were mapped in the upper glacial aquifer on Long Island, N.Y., by G. E. Kimmel and O. C. Braids (1975). The contaminated water flows, because of density differences, to the bottom of the aquifer and then downgradient for 3,000 m and 1,500 m from the two landfills. Dispersion of the contaminants does not extend laterally more than 100 m in the 3,000 m of travel, but longitudinal dispersion is considerable. The coefficient of longitudinal disperson is estimated to be 9.3 m^2/d.

Ground water near the landfills is characterized by dissolved-solids concentrations of as much as 3,000 mg/l, organic-carbon concentrations of as much as 2,250 mg/l, and an extremely pungent odor. Much of the obnoxious character of the water, however, is lost within a thousand metres of the landfills, although the contaminated water remains higher than ambient water in Na, Ca, HCO_3, Cl, and, in some instances, SO_4. Of the elements As, B, Cd, Co, Cu, Fe, Hg, Mn, Ni, Pb, Se, Sr, and Zn, only Fe, Mn, and Se were found to exceed the standards set by the USPHS for drinking water.

Ground-water temperature was as high as 28°C. Most of the heat generated by the landfills is not carried far downgradient with the contaminants but is dissipated near the landfills.

Stream reaeration measurements made with radioactive tracers

R. S. Grant (USGS) made reaeration measurements on 10 small Wisconsin streams (0.01 to 1 m^3/s) by using radioactive tracers and following procedures developed by E. C. Tsivoglou (EPA) (1972). Tracers were released near sewage-treatment-plant outfalls, and the Wisconsin Department of Natural Resources collected BOD data to be used with the reaeration data for waste-load allocation studies on three of the streams. Measured reaeration coefficients (base *e* at 20°C) ranged from 1.56/d ($Q=0.2$ m^3/s) for a short riffle-free reach to 49.5/d for a steep pool and riffle reach. Evaluation of the coefficient *c* in the predictive model, $K_2=c(h/t)$, is in progress; K_2 is the base *e* reaeration coefficient (per hour) for a given reach, *h* is the drop in water-surface elevation in the reach (in metres), and *t* is the time of flow through the reach (in hours).

ENVIRONMENTAL GEOCHEMISTRY

Geochemical survey of Western coal regions

An interdisciplinary reconnaissance geochemical survey of those regions of the Western United States containing economic deposits of coal has been underway since July 1973. This work is directed especially toward an aspect of geochemical variability that is particularly difficult to come to grips with: testing for the presence of regional geochemical patterns in near-surface landscape materials. The work is patterned after the recently completed geochemical survey of Missouri (U.S. Geological Survey, 1973, p. 225–227) and is intended to establish geochemical baselines for the coal-basin landscapes against which future changes can be measured. Work to date has focused on the northern Great Plains and the Powder River Basin and has covered large parts of North Dakota, South Dakota, Montana, and Wyoming, as well as southern Saskatchewan.

R. R. Tidball, J. A. Erdman, and R. J. Ebens, in a geochemical study of ground lichen (*Parmelia chlorochroa*), sagebrush (*Artemisia tridentata*), soil, and soil parent in the Powder River Basin, found that only boron in the soil parent (C horizon) and copper, lead, fluorine, and mercury in ground lichen (the first two elements being measured in lichen ash) exhibit statistically significant variation at scales larger than about 10 km in the basin (U.S. Geological Survey, 1974b). This general lack of important broad-scale variation indicates that basinwide patterns, if present, tend to be weak; any attempts to map them would be

costly. Moreover, the absence of important basinwide patterns means that a basinwide baseline can be defined rather simply as an "expected" concentration or an "expected" range of concentrations. Such ranges for a few trace elements of especial environmental interest are listed here:

Element	*Sampling medium*	*Powder River Basin "baseline" (ppm)*
Cd	Sagebrush ash	2.0–18
Cd	Lichen ash	1.3–9.3
Hg	Sagebrush (dry material)	0.012–0.041
Mo	Sagebrush ash	3.2–17
Pb	A-horizon soil	11–34
Pb	B-horizon soil	12–28
Pb	C-horizon soil	12–25
Se	Sagebrush (dry material)	0.055–1.7

The range is that expected to be found in 95 percent of a suite of randomly selected samples from the basin. Samples with concentrations outside these ranges must be viewed as highly unusual.

An independent study of trace-element variation in surface soil and sagebrush (*A. tridentata*) in the basin by J. J. Connor, J. R. Keith, and B. M. Anderson confirmed the general lack of significant basinwide geochemical patterns in these materials.

Erdman, in a continuing study of the "species effect" in plant chemistry, determined that big sagebrush (*A. tridentata*) is distinct from silver sage (*A. cana*) in 9 of 21 chemical properties measured. Ash of *A. tridentata* is significantly higher in Al, Cr, Fe, Ti, and V and significantly lower in B, Mg, and Sr and also produces significantly less ash upon combustion than *A. cana*.

Urban geochemistry

Geochemical maps of surficial materials in the Front Range urban corridor demonstrate the prominent control of the geochemical environment by the geologic substrate. H. A. Tourtelot and H. G. Neiman (1974) reported that B, Co, Cr, Cu, Ni, Sc, and V are significantly more highly concentrated in areas underlain chiefly by fine-grained rocks of Cretaceous age than they are in areas underlain by rocks of Tertiary age or young wind-blown deposits. In contrast, barium, yttrium, ytterbium, and zirconium display low concentrations in areas underlain by Cretaceous rocks and high concentrations in areas underlain by Tertiary rocks. Imposed upon this basic pattern are local areas exceptionally high in Cu, Pb, Zn, Hg, Mo, Ag, and Sn; these metals are thought to reflect additions from urban technological activities (U.S. Geological Survey, 1974c, p. A205).

One activity that may have an important effect on the geochemical environment is disposing of metal-rich sewage wastes by plowing them into agricultural land. Tourtelot, in cooperation with J. A. Erdman (USGS) and Burns Sabey (Colorado State Univ.), investigated the trace-element changes in wheat grown in sewage-treated experimental plots. Preliminary results suggest that additions of up to 55 tonnes (dry) of sewage per acre result in little change in the total metal concentration in soil, with the noticeable exception of copper and silver. However, the ash of wheat grains grown on treated plots is significantly higher in Ni, Fe, Mn, and Zn and significantly lower in Al and Ba. Nickel exhibits the strongest response.

Geochemistry and health

R. A. Tidball (USGS) and L. A. Selby (Univ. of Missouri) reported that a significantly high proportion of the variations in birth defects reported in swine in Missouri for the years 1969–71 can be described in terms of the gross soil chemistry of the State. Techniques of stepwise multiple regression result in the prediction equation:

$$DF = 69 - 0.6 \log \mathrm{Na} + 2.1 \log \mathrm{Ti} - 930 \sqrt{\mathrm{P}} + 3{,}800\mathrm{P} - 23{,}000\mathrm{P}^2 + 78{,}000\mathrm{P}^3$$

where *DF* is an estimate of the square root of the total birth defect rate in swine by county and Na, Ti, and P are mean soil concentrations of sodium, titanium, and phosphorus, respectively, in percent by county. The terms on the right account for 46 percent of the variation in *DF*. Variations in specific defects related to sensory organs, sex organs, and legs in newborn swine are also moderately well described in terms of soil phosphorus. The importance of phosphorus in predicting these defect rates may reflect some aspect of the extremely important role this element plays in physiological processes.

LAND SUBSIDENCE

Studies of land subsidence caused by the intensive withdrawal of ground water continued in Arizona, California, Louisiana, Nevada, and Texas. Multiple-depth extensometers were installed in Texas and Baton Rouge, La., to measure changes in the thickness of aquifer systems subject to stresses exceeding preconsolidation stress; the deepest extensometer wells are about 900 m deep and utilize free pipes rather than anchored cables. The stress-strain records from these sites, together with those from extensometers in Arizona, California, and Nevada that

have been operating for 5 to 15 yr, should add considerably to the knowledge of the mechanical and hydrologic properties of compressible aquifer systems and the storage characteristics of the interbedded clayey aquitards and confining beds.

Sinkhole problems in Alabama

J. G. Newton (1975), in a cooperative investigation with the Alabama Highway Department, evaluated most areas of recent sinkhole activity in Alabama. Sinkholes, as related to cause, are defined as "induced" and "natural." Induced collapses are by far the greatest problem. It is estimated that 4,000 induced collapses or related features have occurred in Alabama since 1900, most of them since 1950, whereas records indicate that fewer than 50 natural collapses have occurred since 1900; a significant number of these natural collapses may have been related to man's activities.

Most induced sinkholes are caused by declines in the water table; others are caused by construction. Collapses due to construction are caused mostly by diversion and concentration of drainage over air-filled openings in bedrock. Few induced collapses result from roof failures of openings in bedrock; almost all result from failures of the roofs of cavities in unconsolidated deposits that form where deposits migrate downward into openings in underlying bedrock.

Some degree of solution of carbonate rocks precedes the development of all natural sinkholes. The first displacement of the land surface forming a new natural sinkhole results from the continuous solution of bedrock, a natural decline in the water table, or a combination of both. The displacement generally occurs in one of three ways: (1) Roofs consisting of bedrock or of unconsolidated deposits collapse into an opening in bedrock progressively enlarged by solution; (2) cavities in unconsolidated deposits that have formed as a result of their downward migration collapse into underlying openings in bedrock; and (3) slow subsidence results from solution of the upper surface of bedrock or the downward migration of unconsolidated deposits in areas where the rate of subsidence exceeds the rate of deposition. All natural collapses in Alabama are comparable in size to induced sinkholes.

Many sinkholes develop with little or no warning; others are preceded by recognizable features that can be observed on the ground and from the air. Aerial photography and other remote-sensor imagery are used to locate sinkholes and related openings, lineaments, water loss, and vegetative stress or anomalous plant vigor. This information, combined with geologic and topographic maps and available water records, allows an evaluation of sinkhole hazards with a minimum of fieldwork along proposed highway corridors.

Monitor wells installed in Baton Rouge, Louisiana

Large concentrated withdrawals of ground water in the Baton Rouge, La., area had increased to about 5.7×10^5 m^3/d by 1970 and are projected to increase to about 11.4×10^5 m^3/d by 1980, according to G. T. Cardwell. The artesian head in the eight principal aquifers in the freshwater section, which extends to a depth of about 880 m, has declined sharply in recent years. Water-level declines from initial conditions range from a minimum of 35 m ("2,800-ft" sand) to a maximum of about 140 m ("2,000-ft" sand) and averages about 60 m for all aquifers. Leveling by the National Geodetic Survey (formerly the U.S. Coast and Geodetic Survey) in 1965 indicated a maximum subsidence of about 30 cm for the period 1934–65, and measurable subsidence covered 650 km^2 in a bowl-shaped area generally coinciding with the cone of depression. Leveling in 1969, which was part of a Louisiana Water Resources Research Institute project, indicated 9 cm of subsidence in the center of the pumping cone.

In recognition of the need for better information on the rate of subsidence, particularly in the heavily pumped area, the USGS began a data-collection program in fiscal year 1974, in cooperation with State and local agencies. Three specially constructed wells, equipped with extensometer and water-level recorders, were completed. The extensometers monitor compaction or expansion of sediments to depths of 254, 518, and 913 m, which represent the shallow, intermediate, and deep aquifer zones, respectively. The wells are also constructed so that head changes for the "600-ft," "1,200-ft," and "2,800-ft" sands can be monitored.

Land-surface subsidence near Texas City and Seabrook, Texas

R. K. Gabrysch and C. W. Bonnet (1974) reported that pumping of water from the subsurface in Harris and Galveston Counties, Tex., has caused declines in fluid pressure, which in turn have resulted in subsidence of the land surface at Seabrook in Harris County and Texas City in Galveston County. Withdrawals of water by large-capacity wells began in Harris County in the 1890's and in Galveston County about 1894. Artesian-head declines of as much as 73 m in the town of Seabrook and 46 m at Moses Lake

near Texas City have caused 1.01 m of subsidence in Seabrook and 0.55 m at Moses Lake.

The field history of subsidence in relationship to water-level changes and clay thickness was used to predict ultimate subsidence. On the basis of continued loading until 1995, it was estimated that ultimate subsidence in Seabrook and at Moses Lake would be 3.0 and 1.4 m, respectively.

Subsidence bench-mark network established in Tucson, Arizona

A network of leveling controls was established in the Tucson, Ariz., area to monitor possible land subsidence caused by ground-water pumping, according to E. S. Davidson. The network extends from bedrock bench marks across areas of maximum water-level decline and the thickest sections of water-bearing deposits. Where available, old level lines were incorporated in this network. Preliminary results indicate less than 1 cm of subsidence on any of the old lines during the 30 to 40 yr since leveling began.

Land subsidence in southern Idaho caused by ground-water withdrawal

In an area of land subsidence north of Malta, Idaho, heavy ground-water pumping has caused water levels to decline more than 42 m, according to B. E. Lofgren. Releveling of bench marks along State Highway 81 in the autumn of 1974, in conjunction with geothermal studies in the Raft River valley, indicated that there had been as much as 0.8 m of subsidence since 1934 in an affected area of about 100 km^2. A northwest-trending earth fissure first recognized in the early 1960's apparently was caused by horizontal seepage stresses on the western margin of the subsidence depression.

Land-surface changes in San Jacinto Valley, California

A detailed analysis of 4 yr of correlative records of water-level, extensometer, and land-surface changes suggests that there are three types of vertical ground movement in the San Jacinto Valley, Calif., according to B. E. Lofgren (1976): (1) An elastic undulation of the land surface of about 0.02 m/yr in close response to roughly 15 m of seasonal water-level fluctuations; (2) a long-term compaction of water-bearing deposits of about 0.001 m/yr; and (3) a deep settlement of 0.003 to 0.006 m/yr, probably caused by continuing downfaulting in the graben trough. At the extensometer site, the specific compaction of the aquifer system was about 1.3×10^{-2} m of compaction per metre of artesian-head decline, and specific expansion decreased from 1.3×10^{-3} to 0.95×10^{-3} m of expansion per metre of artesian-head rise during the period between 1971 and 1974.

Model parameters for idealized aquitards in the Santa Clara Valley

Twelve years of field records of stress and strain at four sites in the Santa Clara Valley, Calif., and a digital model were used to approximate average values for hydrologic parameters. D. C. Helm (1975) developed a model that computes the compaction of a series of idealized aquitards from known changes in effective stress and from assumed parameter values. The idealized aquitard specifications (characteristic thickness and number) are estimated from the evaluation of a microlog of the real aquifer system. By adjusting parameter values so that computed compaction simulates observed compaction, the "best fit" set of parameter values is considered to be diagnostic for the series of idealized aquitards at a particular site. Preliminary diagnostic constant values for the four sites in the Santa Clara Valley are as follows: vertical hydraulic conductivity ranges from 3.3 to 16.0×10^{-7} m/d; nonrecoverable specific storage ranges from 3.3 to 13×10^{-4} m^{-1}; and recoverable specific storage ranges from 4.9 to 33×10^{-6} m^{-1}. Preliminary stress-dependent estimates for vertical hydraulic conductivity range from 1.3 to 52×10^{-7} m/d, and, for nonrecoverable specific storage, estimates range from 2.4 to 13×10^{-4} m^{-1}.

Land surface in Santa Clara Valley, California, rebounding

Water imports to Santa Clara County through the Hetch-Hetchy and South Bay aqueducts averaged about 171 hm^3/yr in the period 1972–74—only 18.5 hm^3 less than the annual pumpage. About two-thirds of the imported water was used directly, and one-third was delivered to spreading basins to replenish the ground-water supply. J. F. Poland reported that, as a result of the increased imports and the above-average precipitation during those years, the artesian head at the long-time index well in San Jose rose from a spring high of 21 m below land surface in 1972 and 1973 to 18 m below land surface in 1974; it rose to about 12 m below land surface in early 1975, the highest water level since 1946. This rise of nearly 9 m since 1973 was reflected in the response of the water-bearing sediments. During 1974, the land surface rebounded 6 mm, as measured by extensometers in San Jose and Sunnyvale.

ASTROGEOLOGY

PLANETARY STUDIES

Interpretive studies of Mars

D. E. Wilhelms made a detailed comparison of cratered terrains on Mars and the Moon. On the basis of differing crater frequencies, three major types of cratered terrain were mapped. The resulting pattern is similar on both the Moon and Mars, except that the terrains with intermediate crater frequencies are slightly more common on Mars. The similarity in pattern suggests a similar cratering history: an early heavy flux followed later by a much lower flux. The work also pointed to the possibility of massive flooding of intercrater areas within the cratered terrain, probably by old volcanic deposits. M. H. Carr explored possible mechanisms for the formation of a bulge of the Martian crust centered on the Tharsis region. The bulge is several thousand kilometres across and 7 km high at the center. Close to the center are the large shield volcanoes of Tharsis, and radial fractures extend outward from this region to cover almost half the planet. The coincidence of the bulge, the radial fractures, and the planet's most prominent volcanic region suggests that their origins are related. Carr proposed that the bulge formed 1 to 2 b.y. ago and that the fractures resulted from crustal extension during its formation. Volcanism was later preferentially located at the center of the bulge, partly because the intense fracturing allowed easy egress of magma to the surface.

Systematic geologic mapping of Mars

A program of systematic geologic mapping of Mars at a scale of 1:5,000,000 by both university and USGS personnel is approximately one-third completed. In the 11 quadrangles so far mapped, channel deposits generally are in the upper part of the stratigraphic column. They appear to be the same age as the younger plains materials and younger than the volcanic features. However, most of the area mapped so far is within the densely cratered terrane where volcanic features are generally older than those in the sparsely cratered plains. The relative ages of the channels and the volcanic features of the plains are still to be determined. The plains range widely in age, judging from the number of superimposed craters. Many have lobate flow fronts and ridges resembling those on the lunar maria, so that a volcanic origin is suspected. Other plains lack these features but have numerous albedo features that suggest an eolian origin. Several ancient volcanic shields have been recognized in the densely cratered terrane. The large number of impact craters superimposed on these shields indicates formation very early in Martian history.

Topographic mapping of Mars

A new version of the 1:25,000,000 topographic map of Mars incorporates several features not included in an earlier preliminary version made soon after completion of the Mariner 9 mission. Generalized contours have been added. These were derived by combining all available data on Martian elevations into one consistent set. Terrestrial radar, occultations, and the MM'71 ultraviolet spectrometer were the main data sources. These data were referred to a fourth-order harmonic of the planet's figure. Eight 1:5,000,000 topographic maps were completed, each including shaded relief, albedo, and contours.

Viking support

A miniaturized X-ray fluorescence spectrometer was designed, built, and installed on the first Viking lander, which was launched toward Mars in August 1975. The instrument was tested in simulated Martian conditions and returned good-quality data, which permitted the identification of an unknown sample. A bench-top version of the instrument is in operation at Reston, Va. The Viking Inorganic Analysis Experiment, which will utilize the instrument, is being directed by a team of scientists from the USGS and other institutions: Priestley Toulmin III and H. F. Rose, Jr. (USGS), A. K. Baird (Pomona College), B. C. Clark (Martin Marietta Corporation), and Klaus Keil (Univ. of New Mexico).

Mercury

In 1974, Mercury joined the Earth, the Moon, and Mars as a planet for which enough detailed informa-

tion is available to make meaningful geologic comparisons. Mariner 10 flew by Mercury on March 29 and September 21, 1974, and returned over 2,000 close-up pictures. The closest planet to the Sun and one of the smallest major planets, Mercury bears some striking resemblances to and has some intriguing differences from the Moon (Trask and Guest, 1975).

The Mercury pictures support the view that terminal heavy bombardment, dated from lunar samples at about 4 b.y., was an episode that characterized the entire inner solar system. The Earth very probably also underwent a comparable bombardment, which must be included in any reconstruction of terrestrial history. The largest impacts on the Moon and Mercury produced huge basins that were probably excavated initially to a depth of 100 to 200 km; permanent modification of the host material certainly occurred to some appreciably greater depth. Many such events on Earth 4 b.y. ago must have created physical and chemical heterogeneities in the upper mantle and probably reset all radiometric dates.

LUNAR INVESTIGATIONS

Lunar basins

Photogeologic investigations combined with data from lunar mapping, cratering experiments, and remote sensing resulted in revised interpretations of lunar impact-basin development and morphologic expression of accompanying structures and deposits.

J. F. McCauley proposed a revised model for the Orientale basin. In this model, the original rim of the crater formed by the impact event is generally coincident with the crest of the Rook Mountain ring some 600 m in diameter. The knobby material of the Rook Mountain unit, previously described as secondary slump products, is now considered to result directly from the cratering event; its texture and distribution pattern suggest that it is the uppermost part of the overturned flap of the crater rim and that it overlies the radially lineated Hevelius Formation. The coarse knobs represent coherent material quarried from well beneath the lunar low-velocity surface layer (depth about 25 km) that was churned up by pre-Orientale saturation bombardment. These relatively coherent blocks, now seen as widely scattered knobs, had their source deep within the transient crater. Since these materials were the last to leave the crater, they had considerably less radial momentum than the other ejecta facies associated with Orientale, and they were partly confined by the outer ring fault now marked by the Cordillera scarp. The Hevelius Formation, now exposed mostly outside the Cordillera scarp, is ejecta of shallower origin; it is an earlier excavation product that was less cohesive than the knobby unit. The formation consists of ballistically redistributed debris from the heavily cratered upper part of the pre-Orientale surface, and this unit, like its counterpart, the Fra Mauro Formation, records a complex multiplicity of cratering events. The difference in the depth of the source region and the greater radial momentum together account for the distinctive braided appearance.

Ejecta relations similar to those around Orientale are seen in the DOD's experimental crater Dial Pack, which is located in Nevada. Preliminary study and mapping by D. J. Roddy of the structures seen on the floor of this crater and that of the Prairie Flat crater, also in Nevada, suggest that anticlines and domes are present on the floors of these experimental craters, and Roddy and McCauley interpreted the ridges and domes seen within the crackled inner-basin unit of Orientale as analogous compressional features. These features are formed late in the cratering event by inward motion of deep-seated material. The preparation of structural sketch maps of the interior of the basin has led to the recognition of numerous radial faults hundreds of kilometres in length that cut the inner rings into segments and that locally extend outward through the Cordillera scarp. Translations on individual blocks appear to be in the inward direction and to be controlled in part by the lunar grid. These movements are considered to have occurred during the cratering event and are not thought to be related to postcrater slumping. They appear to be similar in general character to some of the tear faults in the walls of Meteor Crater as it was originally mapped by Shoemaker.

D. H. Scott used gravity data to calculate the volume of the Orientale basin where topographic control is inadequate for reliable estimates of basin geometry. The results indicate that the present volume of Orientale is about 2×10^6 km^3 but that the original volume, and thus the amount of material ejected, must have been more than 5×10^6 km^3. Stratigraphic studies using these results, combined with mapping of the ejecta blanket and its distribution, by McCauley and Scott resulted in the subdivision of the Orientale ejecta blanket into six distinct stratigraphic units. These stratigraphic units will be designated as members and formations, and all basin-related materials will be elevated to group

status. The new mapping reconfirmed the asymmetry of the basin ejecta, which are thought to reflect nonvertical incidence of the impacting bolide or the influence of older nearby basins on rock strength, fracture propagation, and the formation of topographic barriers.

Geologic remapping on the central near side of the Moon (50° N. to 50° S., 50° E. to 50° W.) by D. E. Wilhelms, which incorporated the results from sampling and remote-sensing missions of the last 5 yr, led to a reevaluation of features now thought to be related to impact basins. In particular, the rock samples returned by Apollo have necessitated reinterpretation of certain mantles, plains, hills, pits, and furrows of the terrae that were previously thought to be of volcanic or tectonic origin. Most such features on the central near side are now seen to be related to impact basins, especially Imbrium, but also to the younger Orientale and the older Nectaris, Humorum, Serenitatis, and Crisium basins. For example, the Descartes Mountains at the Apollo 16 site are believed to consist of primary and secondary Imbrium material overlying Nectaris material. Secondary craters of basins and the masses of basin ejecta that flowed along the surface are more extensive than was once thought. The ground ejecta arrives at a given radial distance from the basin later than the secondaries. The resulting override of the secondaries produces many of the complex superposition relations that once seemed to require volcanic origins.

Also pertaining to lunar impact basins are studies of gravity anomalies found on the Moon's near side by the Apollo missions and evaluated by Scott. Some of the positive anomalies are nearly circular and probably represent previously unrecognized basins or subbasins. Two lie along a line connecting the Serenitatis and Nectaris mascons; one is centered over the crater Lamont and the other near the old crater Torricelli R north of Theophilus. The gravity data show the probable presence of a large mascon in northern Mare Serenitatis substantiating previous geologic mapping, which postulated that the northern part of this basin was formed by separate impact. Gravity values obtained at two different spacecraft altitudes over Lamont allowed some discrimination in calculating the configuration and depth of this mascon. Calculations indicated that a disk-shaped mass having a radius of about 85 km and a thickness of about 1.8 km would produce the anomaly observed at both altitudes.

Compilation by Scott, J. M. Diaz, and J. A. Watkins of all lunar morphologic features believed to be associated with volcano-tectonic processes such as ridges, troughs, rilles, domes, cones, and lineaments indicated that two major mare-ridge systems are present on the Moon: (1) basin-concentric ridges associated with circular mascons and (2) long linear ridge systems in Oceanus Procellarum that appear to correlate with positive gravity trends. The magnitudes of the gravity anomalies associated with the linear ridge systems are much less than those of the circular mascons. It is thus suggested that a large number of basaltic dikes in themselves are not primary contributors to mascon gravity anomalies. Thus, pluglike mascon models possibly extending through the crust to the lunar mantle seem more appropriate than relatively thin disk-shaped mascons supported by the crust and fed by dikes.

Apollo 17 mission results

B. K. Lucchitta, V. S. Reed, G. E. Ulrich, A. G. Sanchez, and E. W. Wolfe continued to study the Apollo 17 landing region. Using both photogeologic interpretation and the gravity data of D. H. Scott, which indicate that Mare Serenitatis is underlain by two basins instead of one, Wolfe and Reed suggested that the Apollo 17 landing area is located approximately at the third ring of a basin structure similar to but slightly larger than the fresher Orientale basin. The strikingly similar shapes, sizes, and distributions of the massifs and sculptured hills in the Taurus-Littrow area and the massifs and related knobby-textured terrane in the outer Rook Mountain ring (ring 3) of the Orientale basin indicate that these are analogous structural features. Extrapolating from ring 3 of the Orientale structure, which has been interpreted as the approximate rim of the transient cavity, to the slightly larger third ring of the southern Serenitatis basin structure, Wolfe and Reed estimated that perhaps 15 km of ejecta was emplaced adjacent to the southern Serenitatis transient cavity. Subsequent development of the ring structure and the radial grabens and emplacement of more ejecta created the mountainous landscape that was later flooded by mare basalt to form the Apollo 17 landing valley.

The investigative team summarized the geology of the landing valley as follows: the radial graben in which the Taurus-Littrow valley is located was partially filled by about 1,400 m of basaltic lava. The uppermost part, texturally variable but chemically uniform olivine-normative basalt, may be on the order of 100 m thick. Large boulders of quartz-

normative basalt on the rim of Camelot Crater may represent an underlying flow unit. Basalt extrusion in the valley terminated about 3.75 b.y. ago and was quickly followed by deposition of a unit of glass beads of probable pyroclastic origin. A remnant of this unit in the Shorty Crater target is represented by orange and black droplets on the Shorty Crater rim. The glass-bead unit in combination with the overlying regolith forms an unconsolidated surficial deposit with an average thickness of about 14 m, thick enough to permit abnormally rapid degradation of the smaller craters, especially those <200 m, so as to create a subdued appearance. Admixture of glass-bead material gives the surface a distinctive dark color, which, in combination with its subdued appearance, led to the erroneous premission interpretation of a young dark mantling unit of pyroclastic origin. Impact-generated regolith consists mainly of local materials from the subfloor basalt, the glass-bead unit, and the nearby highlands. In its upper part, the regolith contains basalt-rich ejecta from crater clusters that pepper the valley floor. Most of the craters are part of a secondary cluster formed by projectiles from Tycho; the light mantle is a deposit of secondary ejecta or an avalanche or both, set in motion by the impact of Tycho secondary projectiles on the South Massif. The central cluster and the light mantle, and hence Tycho, were probably formed between 15 to 20 and 70 to 95 m.y. ago.

In order to elucidate the relationship between dark mantle and orange materials in the landing area, Lucchitta (USGS) and H. H. Schmitt (NASA) investigated a dark mantle area on the opposite side of the Serenitatis basin. Orange and red material had been observed and photographed during the Apollo 17 orbital paths in that area, and a later examination of photographs showed that it occurs only within the dark mantle that overlies old rilled mare and highland units and is absent on the younger mare unit in this area. The orange and red material occurs predominantly as halos, patches, or rays around fresh impact craters ranging in diameter from less than 50 to 250 m and in layers exposed at the base of the dark mantle deposit in the sweep walls of a depression and a graben. Red material is present in the highland subsurface, possibly as dikes. The study suggested that orange material, locally underlain by red material, occurs in the dark mantle to a depth of about 50 m as locally stratified but discontinuous pyroclastic materials that erupted during the later stages of accumulation of the older mare basalt units. These observations confirm that the geologic settings of dark mantle areas on both sides of Mare Serenitatis are similar.

Craters

Testing extraterrestrial craters and candidate terrestrial analogs for morphologic similitude was treated by R. J. Pike as a problem in numerical taxonomy. According to a principal-components solution and a cluster analysis, 402 representative craters on the Earth, the Moon, and Mars divide into two major classes with contrasting shapes and modes of origin. Craters of net accumulation of material (cratered lunar domes, Martian "calderas," and all terrestrial volcanoes except maars and tuff rings) are in a group apart from craters of excavation (terrestrial meteorite-impact and experimental explosion craters, typical Martian craters, and all other lunar craters). Maars and tuff rings belong to neither group but are transitional. The classification is based on criteria of topographic geometry. Of these, the morphometric differences between crater bowl and raised rim are the strongest. Although single topographic variables cannot confidently predict the genesis of individual extraterrestrial craters, multivariate statistical models constructed from several variables can distinguish consistently between large impact craters and volcanoes.

TERRESTRIAL ANALOGS AND EXPERIMENTAL STUDIES

CRATER INVESTIGATIONS

Lonar Crater

A geologic investigation of Lonar Crater in Maharashtra, India, by the Geological Survey of India, with the participation of D. J. Milton (USGS), has been in progress. The crater is 1,830 m across and nearly 150 m deep. It is similar in structure, age, and state of preservation to the better known Arizona Crater. The crater is in the Deccan Traps, the only terrestrial crater known in basalt, and so presents petrographic features particularly analogous to crater materials on the Moon. Earlier results (Fredriksson and others, 1973) for the first time established the impact origin on the basis of shock features, including shock-melted basalt bombs and spherules in the ejecta, isotropized plagioclase in moderately shocked fragments, and shatter coning in weakly shocked breccia in drill cores in the crater floor. As

yet, no meteoritic material has been identified. Current investigations center on the mode of deposition of the ejecta. Ejecta-filled depressions in the substrate near the outer margin of the ejecta blanket are apparently secondary impact craters. Fragments of substrate soil are incorporated into the basal parts of the ejecta blanket. Their distribution is being studied for its relevance to the mixing of lunar breccias.

Ries Crater studies

A complete suite of shocked granodiorites from the Ries Crater suevite was assembled by E. C. T. Chao, J. A. Minkin, and C. L. Thompson and classified according to the degree of shock from 1 to 7 on the basis of shock features observed in quartz, plagioclase, and biotite. The correlation of microscopic and megascopic classifications of the degree of shock was established for the first time.

Samples of shocked granitic pegmatite from Lake Lappajarvi, Finland, were chosen for detailed systematic study by optical, X-ray, and electron microscope techniques. These samples, the best naturally shocked specimens that the investigators have seen, contain large single crystals of shocked quartz and feldspar and cover a complete range of the degree of shock. Several single crystals of shocked quartz studied by X-ray precession technique were all found to be Dauphinê twinned, even crystals that were only very weakly shocked as judged by refractive indices and lack of lamellar features. The consistent presence of Dauphinê twinning in weakly shocked quartz crystals indicates that it may be a dominant form of yielding in quartz at low shock pressures.

Elko craters, Nevada

A field of probable impact craters near Elko, Nev., was studied in reconnaissance by D. J. Roddy. An aerial search extended the known length of the field from 20 to 21.5 km to the northeast, with a maximum width of 2.7 km. The total number of craters recognized now exceeds 200. Aerial reconnaissance of many hundreds of square kilometres surrounding this area located only one other small field 8 km west, which contains several small craters less than 10 m in diameter. The larger craters in the main field are as deep as 3 m and have well-defined rims. Both single and multiple craters are common; the largest multiple crater is approximately 250 m across. Most of the craters tend to occur in clusters of three or more and are concentrated along a northeast-southwest centerline; single isolated craters are most common along the outer edges of the field. The fact that the crater distribution does not appear to be influenced by topographic or structural control strengthens the impact hypotheses. Soil samples from the largest Elko craters have been examined for magnetic, glassy, and shocked materials. To date, only magnetite, derived from mineralized zones that lie 3 to 4 km to the west, has been identified.

Shock-wave-cratering mechanics, impact, and explosion cratering

D. J. Roddy participated in large-scale explosion experiments conducted by the DOD in both Canada and the United States over the last decade. These experiments have repeatedly yielded similar types of structural deformation in craters formed from hemispheres and spheres of high explosives detonated at and above the ground surface. Structural deformation in these craters, which are up to 100 m in diameter, includes central uplifts, inward and upward movement of the crater floor, faulted, folded, and uplifted rims, and massive overturned flaps with raylike extensions. Other aspects common to these craters include the ballistics and distribution of ejecta, fused material, shatter cones, and certain types of solid-state shock-metamorphic features, such as planar elements formed under shock-wave pressures in crystal lattices.

The craters formed in these explosion experiments provided the confirmation necessary to show that certain types of major structural deformation are related to charge size and geometry and to height of burst and that target media are critical but do not control the basic styles of deformation.

Several of these cratering experiments were used for astronaut training and in the NASA-sponsored USGS lunar geologic surface experiments. The topographic and structural similarities between these and earlier craters generated by surface explosions and terrestrial, lunar, and Martian craters have been of assistance in discussing the hypervelocity impact origin and in understanding large-scale impact cratering processes.

The cratering sequences determined in these experiments reemphasize their similarities with craters formed by hypervelocity impact and shock vaporization of a low-density body, such as a comet, which does not penetrate deeply and produces a surface-generated very high energy shock wave. The numerous structural similarities between these surface-generated explosion craters and certain very large terrestrial and lunar craters up to tens of kilometres across suggest that this analogy can be extended to include the largest of the natural sites. For example,

an unusually good morphological comparison can be made between Mixed Company 3, Snowball (500-t TNT surface hemisphere), and the lunar crater Copernicus (95 km across). A similar comparison can be made between the Prairie Flat (500-t TNT surface sphere) and Dial Pack (500-t TNT surface sphere) craters in Nevada and the ringed lunar structure Mare Orientale (over 1,000 km across).

MINERALOGICAL INVESTIGATIONS

Mars eolian winnowing simulated

J. G. Hammarstrom and Priestley Toulmin III carried out size and mineral analyses of material delivered to a model of the Viking X-ray fluorescence spectrometer (XRFS) in a series of wind-tunnel tests simulating atmospheric conditions on the Martian surface. The original material was a mixture of quartz, augite, magnetite, and muscovite, each sized to approximate the grain-size distribution of the lunar fines. The material was dropped from a Viking sampler head into a Viking XRFS funnel from several heights at different wind velocities and directions. Analysis of the material that actually got into the funnel confirmed the expected dependencies on height, wind, density, and shape but indicated that, if the sampler head is placed close to the funnel, even high winds (up to 70 m/s) should have very little effect on the sample composition.

Fluid inclusion studies on simulated Martian samples

Edwin Roedder studied some simulated Martian samples in an attempt to evaluate the effects of various suggested sterilization procedures on the scientific information obtainable from a returned Mars sample. Fluid inclusion studies are particularly appropriate here in that they can yield much information from very tiny samples, even those in the 1-μg range. Although almost any sterilization protocol would seriously affect or totally negate the results of at least some petrological, geochemical, or geophysical experiments performed on the samples, Roedder found that sterilization at 275°C for 1 d in helium at 1 atm had almost no noticeable effect on the significance of the data obtainable from a study of fluid inclusions. However, these results cannot necessarily be extrapolated to higher temperatures or to other types of sample materials.

Experimental shock research

The transmission interference microscope is a powerful tool for the study of microstructures such as closely spaced parallel fractures, twinning, and lamellar structures produced by static and shock deformation. In an investigation of experimentally shocked quartz conducted by E. C. T. Chao, it was possible to distinguish microfractures from lamellae only by this technique.

LUNAR SAMPLE INVESTIGATIONS

Petrology of lunar rocks

During the Apollo 17 mission, several large boulders of highlands rock derived from the North and South Massifs were sampled. Samples were selected to represent the major rock types in each boulder, and the field relations were carefully documented. In recognition of the unique value of these samples, interdisciplinary consortia of investigators were established to study the suites of rocks from each boulder. E. C. T. Chao led the consortium studying samples collected from the boulder at Station 7. A similar consortium led by O. B. James was established to study two samples from Station 3 (although these rocks were collected from regolith, they appear to be related to samples taken from a boulder at Station 2).

Four samples (77135, 77115, 77075, and 77215) were collected from the boulder at Station 7. Studies of these samples by Chao, J. A. Minkin, and C. L. Thompson (1974) led to the following conclusions:

1. Sample 77215, the oldest of the four samples as determined by field relations, is a breccia containing fragments of norite. The norite appears to be of relatively deep-seated origin, for it contains orthopyroxene grains with thick exsolved lamellae of augite. Some impact process excavated the norite and brought it to the upper levels of the lunar crust.
2. Samples 77075 and 77115 crystallized from fragment-laden melts that diked and enclosed, respectively, the mass from which 77215 was taken. Field relations suggest that these two melts could have been contemporaneous, formed by the same event.
3. The rock units from which 77075, 77115, and 77215 were taken are shock fractured as a block; this block is enclosed by unfractured feldspathic pigeonite basalt, represented by 77135. Sample 77135 crystallized from a fragment-laden melt formed in an event that took place after the 77075 and 77115 melts formed.
4. Detailed studies of 77135 suggest three possible sources for the melt from which it crystallized: (1) An impact melt formed by the Serenitatis

event, (2) an endogenous igneous melt unrelated to the Serenitatis event, or (3) a premare endogenous igneous melt intruded into the wall of the Serenitatis basin after the basin was formed. Regardless of the source of the 77135 melt, this rock represents one of the major rock types of the lunar highlands.

Studies of the Station 3 consortium have thus far concentrated on sample 73215 (James, 1975a). The bulk of this breccia consists of an aphanitic matrix containing competent mineral and lithic clasts plus bands and patches of granulated clastic materials. The matrix is quite variable, and several types are distinguishable; these vary in color, cohesiveness, content of shear-induced porosity, and content and composition of clast-derived schlieren. The consortium studies, which thus far have been primarily of matrix, have shown that all types of matrices consist of abundant small lithic and mineral clasts set in a dark groundmass of minute grain size and that the groundmass crystallized from a melt. It is unlikely that this breccia originated as regolith breccia or unconsolidated regolith in which an original fragmental glassy matrix was melted by a shock or thermal event. Instead, characteristics of the rock texture and fragment assemblage suggest that the breccia represents an aggregate of impact melt (which crystallized to form the groundmass) and pulverized rock, all of which formed in a large impact event; the event may have been one of the basin-forming impacts. The rock shows well-developed structures formed by differential flow and shear of the matrix and clast materials, and these structures demonstrate that shear and flow processes may have been very important in lunar highland breccias.

One particular class of lunar breccias holds great potential for study of the early history of the lunar crust. This class formed as a result of major impacts that generated mare basins and the largest lunar craters. Such impacts would have excavated rocks from an extensive section of the lunar crust, and from these a partial reconstruction of the preimpact crust could be made. James (1975b) evaluated the different types of lunar breccias in an attempt to identify those that may have had major-impact origins, and it appears that many types may indeed be related to major impacts. Apollo 17 light-gray breccias may be analogous to terrestrial suevites. Many different types of lunar breccias formed as aggregates of melt plus fragmental debris; among these are Apollo 17 blue-gray breccias, green-gray breccias, some of the light-gray breccias, Apollo 16 poikilitic rocks, and the most common types of clasts in Apollo 14 thermally metamorphosed breccias and Apollo 16 friable feldspathic breccias. These types of breccia differ primarily in ratio of fragments to melt and crystallization history of the melt, but bulk compositions of the aggregates are all quite similar. Rock textures and fragment assemblages suggest that all these types of breccia formed as aggregates of impact melt and crushed rock generated during major impacts. Other types of lunar breccias related to major impacts are (1) cataclastic anorthosites, in which the cataclasis was the result of shock during an impact, and (2) "black and white rocks" (which consist of cataclasites diked by fragment-laden impact melts and subsequently remobilized), in which the cataclasis, intrusion by impact melts, and remobilization were all impact induced.

A glass-coated half-metre boulder was sampled by the Apollo 17 astronauts at Station 8, near the front of the Sculptured Hills. E. D. Jackson, R. L. Sutton, and H. G. Wilshire (1975) studied the returned samples of this boulder. The rock is a coarse-grained (0.5 cm) plagioclase-orthopyroxene cumulate and is the only true norite among the returned lunar samples. Lunar surface photographs of the boulder showed it to contain at least nine structural surfaces and four glass veins. Hand-specimen examination of three of the returned samples resulted in the identification of six surfaces and one vein. One of the structural surfaces visible in the boulder was identified as a primary cumulus planar lamination folded through an angle of at least 35° between two oriented samples; fracture sets representing the other structural surfaces were coincident. The boulder is believed to be a sample of the deeper highlands or submare lunar crust, derived from a depth of 8 to 30 km; it was somewhat shock metamorphosed during at least two impact events. The cumulus texture of the rock precludes its being representative of any magmatic liquid composition and suggests that plagioclase sank, not floated, in at least some of the magmatic liquids that formed the lunar crust. Moreover, the evidence that cumulus processes have operated in the lunar crust indicates that the crust is probably heterogeneously layered.

Wilshire, D. E. Stuart-Alexander, and E. C. Schwarzman completed a comprehensive study of Apollo 16 breccias. They consider that all major types were derived by rebrecciation of a first-cycle breccia that consisted of clasts of feldspathic plutonic rock in a matrix of fine grain size. The first-cycle breccia, because of the nature of its clast assemblage, is thought to represent material derived from consider-

able depth in the lunar crust and excavated by a basin-forming event. Relict clasts that survived the brecciation processes show that the feldspathic plutonic rocks originally formed as igneous cumulates; however, thermal metamorphism caused local recrystallization in most of these clasts. The first major impact event that affected these rocks produced extensive pulverization, melting, and thermal metamorphism.

Wilshire (1974) summarized some of the most important characteristics of the provenance of lunar highland breccias. These breccias contain relics of plutonic source rocks that have had long igneous and metamorphic histories. Most of these plutonic rocks have extremely feldspar-rich bulk compositions. The compositions and textures indicate that the rocks must have formed by igneous fractionation and that they had lengthy periods of postconsolidation annealing in environments not frequently plumbed by impact. These characteristics are consistent with formation of the rocks in a plutonic environment at depths perhaps greater than 10 km, from which they were excavated by large basin-forming impact events.

Edwin Roedder (USGS) and P. W. Weiblen (Univ. of Minnesota) (1975) reported an anomalous type of silicate melt inclusion of unexplained origin in the Apollo 17 mare basalts. Ilmenite crystals in all seven mare basalt samples examined contain relatively large silicate melt inclusions. These are now either wholly glass or glass that contains a few feathery crystals. Bulk compositions are of two types. (Some individual small ilmenite grains have both types of inclusions.) The less abundant type is of potassic granite composition (6.4 percent K_2O and 76.7 percent SiO_2) and formed by late-stage immiscibility of the silicate melt; similar inclusions are found in most lunar mare basalts and some terrestrial basalts. The more abundant type has identical SiO_2 content, 76.4 percent, but only 0.03 percent K_2O (average of 29 analyses); the difference is made up largely by an increased CaO content, and most other oxides have similar concentrations in the two types. At present, none of the theories proposed for the origin of these anomalous "low-potassium" inclusions satisfactorily explains all the observations.

Experiments on the partial melting of pyroxenes at 1 atm (J. S. Huebner, 1975) suggest that the silica content of a primary mare basalt magma may indicate its depth of origin. During partial melting of augite, aluminum and titanium are strongly fractionated into the liquid phase, and its silica activity is depressed. Thus, melts coexisting with augite can have as few as 1.75 cations of silicon per 6 oxygen atoms. During partial melting of the calcium-poor pyroxenes, orthopyroxene, and pigeonite, aluminum and titanium are even more strongly fractionated into the liquid phase. However, in the case of these pyroxenes, there is a lower limit below which the silica activity of the coexisting partial melt cannot be depressed. If the silica content of a melt coexisting with a calcium-poor pyroxene drops below about 1.9 cations per 6 oxygen atoms, the pyroxene is converted to olivine, and silica is released to the liquid. Experimentally produced melts coexisting with calcium-poor pyroxene (and minor olivine) commonly have about 1.9 cations of silicon and 0.5 cations of aluminum per 6 oxygen atoms. The silicon content of lunar mare basalts ranges from 1.66 to 1.86 cations per 6 oxygen atoms. Therefore, these melts cannot be in equilibrium with, or derived from the low-pressure partial melting of, mantle consisting of calcium-poor pyroxene plus or minus olivine. However, the increasing pressure of the partial melting of calcium-poor pyroxene will progressively decrease the silica content of the coexisting melt. Silica contents of the mare basalts suggest that their parent magmas may have formed by partial melting over the pressure range of 2 to 25 kb, the less silicic of the melts being derived at the greater pressures.

Lunar glasses and lunar fines

R. B. Finkelman, Sol Berman, R. P. Christian, E. J. Dwornik, J. R. Lindsay, H. J. Rose, Jr., and M. M. Schnepfe studied the mineralogy and chemistry of the ultrafine fraction of Apollo 16 regolith samples. Some of their data were reported by Finkelman, Christian, Schnepfe, and Berman (1975). The Apollo 16 ultrafines (less than 30 μm in size) show a more restricted mineral assemblage than the Apollo 14 ultrafines. The fact that particles of mare-derived ferromagnesian minerals are sparse indicates that the range over which significant transport of ultrafine crystalline particles can take place is less than the distance from the Apollo 16 site to the nearest mare surface. The ultrafine fraction has a higher excess reducing capacity than the coarser fraction (30 μm to 1 mm); this difference indicates that the ultrafine particles have been exposed at the lunar surface for longer times on the average than the coarser particles. The ultrafines are enriched in Pb, Zn, Ba, Ga, Rb, Sc, and Yb and depleted in Co and Ni relative to the coarser fractions. The observed elemental enrichments may be due to one or more of the following processes: (1) Volatilization and subsequent condensation (since

the ultrafines have a relatively greater surface area than the coarser fractions, enrichment of condensing volatiles would be greater); (2) an influx of minute grains of KREEP-rich material; and (3) comminution of mesostasis of locally derived rocks.

A. N. Thorpe, F. E. Senftle, C. L. Briggs, and C. C. Alexander (1973) studied the magnetic susceptibility of 11 small glass spherules and 2 samples of a large spherical glass shell from Apollo 15, 16, and 17 fines. Measurements were made over temperatures ranging from room temperature to the temperature of liquid helium. All but one specimen showed the presence of antiferromagnetic inclusions. Measurements of the magnetic susceptibility on five specimens at closely spaced temperature intervals below 77°K showed antiferromagnetic temperature transitions (Néel transitions). In one specimen, these transitions could be ascribed to ilmenite, but, in the other four, they do not correspond to transitions in any known antiferromagnetic compounds.

Age determinations

The uranium, thorium, and lead concentrations and the lead isotopic compositions of selected Apollo 17 soil and rock samples were studied by Mitsunobu Tatsumoto and P. D. Nunes. Concordia treatment of the data for the mare basalts and highland rock samples suggests several early thermal events approximately 4.5 b.y. ago.

Current information from all uranium-thorium-lead lunar chronology data suggests that the Moon had a multistage uranium-lead evolution history, probably dominantly caused by complex planetary bombardment from 4.5 to 3.9 b.y. ago. Events at approximately 4.0, 4.2, and 4.4 to 4.5 b.y. are evident on whole-rock frequency versus $^{207}Pb/^{206}Pb$ age histograms. Each of these events in itself probably reflects multiple cratering episodes. For mare basalts, it appears that complete resetting of the source-rock uranium-lead systems was often approached after a major planetesimal impact (caused by lead loss relative to uranium). It further appears that, during later melting and extrusion of the basalts, 500 to 800 m.y. after basin formation, the uranium-lead total-rock systems were negligibly disturbed, whereas the $^{40}Ar/^{39}Ar$ whole-rock and rubidium-strontium mineral systems were completely reset.

Chemical composition

The Surveyor 3 spacecraft landed at the Apollo 12 site 31 mo prior to the Apollo mission and scooped up a sample of regolith. During the Apollo 12 mission, the astronauts retrieved the Surveyor scoop and the lunar fines (sample 12029) therein. The results of analyses of this material by E. J. Dwornik, C. S. Annell, R. P. Christian, Frank Cuttitta, R. B. Finkelman, D. T. Ligon, Jr., and H. J. Rose, Jr., led to the following conclusions: (1) The green glass components in the fines appear to have been derived from anorthositic norite or troctolite parent materials; (2) the presence of a significant meteoritic component is indicated by relatively high nickel content, abundant metallic iron-nickel blebs and spheres (diameters less than 20 μm), and sparse particles of a copper-rich phase; and (3) the fines had a genesis and history like those of fines sample 12070, collected on the rim of a small crater about 165 m to the northwest.

Twenty-four samples of rocks and fines returned by the Apollo 17 mission have been analyzed by Rose, Cuttitta, Sol Berman, F. W. Brown, M. K. Carron, Christian, Dwornik and L. P. Greenland. Some of their data have been reported by Rose, Christian, Dwornik, and M. M. Schnepfe (1975). The fines samples are extremely variable in composition, but these compositions fall into three broad groups: (1) Light mantle and South Massif fines, (2) dark mantle and valley floor fines, and (3) North Massif fines. One of the analyzed fines samples, 76501, is unique, and its composition cannot be explained by mixing of the three groups listed above; it is depleted in most trace elements relative to the other samples. The dark mantle and valley floor fines samples are compositionally similar to fines collected at the Apollo 11 site, except that the former have a smaller excess reducing capacity and a higher nickel-iron ratio than the latter; the differences suggest that the fines at the Apollo 11 site had a greater exposure to solar-wind irradiation but contain a smaller meteoritic component than the fines on the valley floor at the Apollo 17 site. The Apollo 17 mare basalts all appear to have had a common source; their compositions are similar to those of the Apollo 11 mare basalts. Comparisons of compositions of the regolith breccias and fines samples at Van Serg Crater yield important information on the process of breccia formation: The breccias are identical in composition to unconsolidated regolith, and they probably represent regolith indurated or compacted during the impact event that formed the crater.

REMOTE SENSING AND ADVANCED TECHNIQUES

EARTH RESOURCES OBSERVATION SYSTEMS (EROS) PROGRAM

The EROS program continued to support and coordinate the applications research involved in LANDSAT (formerly ERTS) experiments and remote-sensing applications demonstrations within various Bureaus and Offices of the Department of the Interior. Special emphasis was placed on making the program more responsive to users' needs; significant improvements were made at the EROS Data Center (Sioux Falls, S. Dak.) in production scheduling, reproduction of remote-sensing data, number and types of training programs, and staffing to assist users with application problems.

Additional user-assistance centers, offering varying degrees of service, were developed. Comprehensive services, including assistance in the ordering and analysis of data, and access to data-manipulation equipment and basic remote-sensing literature are now available at six locations in the United States and the Canal Zone.

Costs and benefits of operational ERS systems

A 3-yr study to develop information about the economic, social, and environmental benefits of an ERS satellite system was completed. The study was conducted under an EROS contract by the Earth Satellite Corporation (1974); the firm of Booz, Allen, and Hamilton served as subcontractor. Principal emphasis was placed on a benefit-cost analysis of three ERS systems postulated for the 10-yr period 1977–86: an aircraft system, a one-satellite system, and a two-satellite system. Ranges were developed for both the costs and the benefits of each system. For each alternative, the benefit-cost ratio was less than 1 for the low ranges and greater than 1 for the high ranges. Many of the diverse benefits recognized, including significant social, educational, and environmental benefits, could not be quantified, although such benefits may be substantial. The clear implication is that the computed benefits are conservative and that additional experience, research, and analyses are needed to evaluate the net value of future operational ERS systems.

ERTS–1, A New Window on Our Planet

An EROS-sponsored compilation of brief reports relevant to the missions of the Bureaus of the Department of the Interior was prepared by scientists active in research with imagery and (or) DCP information from the first Earth Resources Technology Satellite (ERTS–1, renamed LANDSAT–1). The 85 different reports (USGS Professional Paper 929) represent documented examples of scientific and operational applications of ERTS–1 data to certain types of geologic, hydrologic, cartographic, biological, and other environmental studies and programs.

Oil-slick detection with LANDSAT data

Morris Deutsch (USGS), in collaboration with Alan Strong (NOAA), determined that major oil slicks on marine water can be detected by LANDSAT. By employing optical techniques for processing MSS data, it was possible to separate and color code (1) oil floating on coastal waters, (2) water not covered by oil, and (3) submerged features such as shallow reefs and kelp beds. Optical enhancements were prepared for apparent oil slicks on the Gulf of Suez, the Mediterranean Sea, and the Atlantic Ocean near Assateague Island, Va.

Linear features of the conterminous United States

Studies of the linear and curvilinear features identified on the LANDSAT mosaic of the conterminous United States (1:1,000,000 scale) by B. K. Lucchitta, G. G. Schaber, and W. D. Carter continued. Selected areas were enlarged to scales of 1:250,000 and compared with geologic maps of the same areas. Although the maps showed considerably more detail, there was a high correlation between major features identified on the mosaics and those shown on the maps. There were other features identified on the mosaics that did not correlate with mapped features and are yet to be explained. These anomalous areas will be compared with geophysical information where it exists. Where such information is lacking, anomalies may suggest areas where future geophysical studies should be undertaken. E. H. Lathram compiled information for the western third of the United

States as part of the Circum-Pacific Cooperative Mapping Program, using the interpretations described above as a base for the conterminous United States.

WESTERN REGION

Remote-sensing techniques aid agriculture

W. A. Lidster (Bureau of Reclamation) reported that satellite data may benefit irrigators in the arid West by providing an early warning system to detect potential seepage problems on irrigated lands. Studies being conducted by the Remote Sensing Institute of South Dakota State University with EROS funds are showing significant correlation between water-table depth and remotely sensed data. A multiple-regression analysis utilizing aircraft and LANDSAT–1 data resulted in a 91-percent-correct classification of water-table-depth occurrence (greater than or less than 2 m). These results indicate that LANDSAT data may provide reliable indications of water-table depth; thus, some optimism is warranted for using this technology in developing an early warning system for detection of water tables approaching 2 m. Such a system would provide sufficient lead time to design protective drainage works without loss of crop production due to a high water table.

Remote sensing of Elephant Butte-Fort Quitman project

The Remote Sensing Center at Texas A&M University, under an EROS-funded contract from the Bureau of Reclamation, carried out research on the use of remote-sensing data from LANDSAT in the management of irrigation projects. The Elephant Butte-Fort Quitman project along the Rio Grande River was used as a study site. Initial work was done in developing a data base of satellite images that provide agricultural and mineral-resource information. Through various interpretive and analytical techniques, information was derived that can be utilized in the formulation of a regional development plan. Darrell Mach (Bureau of Reclamation) coordinated the efforts of the university with the ongoing Rio Grande Regional Environmental Project.

Space data aid lineament analysis

Paul Merifield and Donald Lamar (California Earth Science Corporation) continued their contract study of lineaments on LANDSAT and Skylab images and the relation of these lineaments to fault tectonics and earthquake hazards in southern California. They reported that northeastern, northern, and northwestern lineaments on the images commonly coincide with known faults and that some represent previously unmapped faults. One, the Thing Valley fault, seems to be offset right laterally between 700 and 1,300 m by the Elsinore fault. Northeastern and west-northwestern faults are truncated by major northwest-trending faults and seem restricted to basement terrane. Spectral studies in the Mojave Desert using band-ratio techniques showed a general correlation between spectral levels and the age and elevation of alluvial surfaces.

LANDSAT data useful in range management

E. L. Maxwell and G. R. Johnson (Colorado State Univ.) (1974) studied the usefulness of LANDSAT and other remote-sensing systems as rangeland management tools. A field measurement program supported and verified the successful use of LANDSAT imagery for computer classification of vegetation type, range condition, and green biomass. Biomass classification was accomplished on three successive LANDSAT images without retraining the computer; this achievement indicates that biomass classification may be less critical than expected. Extensive statistical analysis of LANDSAT data has shown that the MSS band 5 and the ratio of band 7 to band 5 are the most significant data for vegetation type and biomass classifications. Cross-classification results of vegetation type and biomass provide a basis for summarizing biomass availability by species group and by the area covered by each group. A 256,000-ha region was automatically classified for less than $500, this accomplishment suggesting that satellite imagery is a feasible range-management tool.

Spatial precipitation estimation using space data

P. A. Davis and S. M. Serebreny (Stanford Research Institute) (1974) analyzed polar-orbiting-satellite data in developing and testing a technique for estimating spatial precipitation over the mountainous terrane of northwestern Montana. The study was supported jointly by the USGS, the Bonneville Power Administration, and the U.S. Army Corps of Engineers. Cloud patterns, classified on visible or infrared images, were used to characterize circulation and saturation over time and space. Tests of the precipitation estimation technique showed excellent results for the April-June period and a moderate underestimate for the October-December period. The same cloud category for a given basin in different seasons tended to occur with approximately the same probable basin precipitation. Temporal changes in the measurements of snow extent over a given basin

varied in the same manner as the measurements of snow depth and water content. The fact that spatial differences between the snow extent in two basins did not correspond to the differences between snow depth and water content suggested a significant variation in terrane influence on precipitation.

Tectonic and resource significance of geostructures

E. H. Lathram, assisted by N. R. D. Albert and R. G. Raynolds, continued his study of the giant (>1,000 km) linears seen for the first time on Nimbus images and LANDSAT mosaics of Alaska and the Western United States. The study concentrated on characterizing major geologic differences on opposite sides of selected linears in order to identify the giant linears that have significantly influenced the tectonic developments of large parts of Alaska and may have influenced the movement of mineralizing solutions and consequently the localization of mineralized areas. Three major, nearly orthogonal sets of such linears have been recognized; many of the giant linears separate areas showing significantly different geologic or tectonic histories (Lathram and Albert, unpub. data, 1975).

Pacific Northwest demonstration project

In response to the request of resource-agency personnel of the Pacific Northwest States and the Land Resource Inventory Task Force of the Pacific Northwest Regional Commission for recommendations on the use of remote sensing in State resource inventory and management problems, the EROS program and Ames Research Center (NASA) suggested the establishment of a Pacific Northwest demonstration project. The project, which was approved by the Governors of Idaho, Oregon, and Washington in October 1974, was entered into jointly by the Commission, the Department of the Interior, and NASA. Land-resource analyses and inventories of selected areas are being conducted at Ames Research Center by employees of the Pacific Northwest States, who receive support, assistance, and guidance from USGS and NASA resource and technology specialists and use both satellite and high-altitude-aircraft data provided by EROS and NASA. The goal of the project is to equip State resource-agency personnel with the knowledge and skills necessary to utilize the synoptic, multispectral, multitemporal, and digital characteristics of LANDSAT data and thereby provide the information required to formulate appropriate and effective management decisions. Problem areas for initial studies have been identified by 28 participating State agencies, a number of workshops have been held, and specialists from the EROS Data Center, the USGS Geography Program, and NASA/Ames have been working with State personnel.

Resource inventory for the Crow and Northern Cheyenne Indian Reservations

The Raytheon Company (1975), under an EROS-funded Bureau of Indian Affairs contract, made a study of the comparative usefulness of LANDSAT data and aerial photographic data in taking a resource inventory on the Crow and Northern Cheyenne Indian Reservations. LANDSAT was found useful for collecting broad-area data on forest stand distribution, surface and subsurface hydrology, land use, and landforms. The cost savings projected for the use of LANDSAT data were substantial in comparison with the cost of generating information of equal detail from the aircraft images.

CENTRAL REGION

Estimates of center-pivot irrigation systems from LANDSAT images

Center-pivot irrigation systems are readily observed on LANDSAT images, particularly on band 5 (600 to 700 nm), where the contrast between irrigated and nonirrigated areas is marked. In recent years, deployment of center pivots has increased rapidly; Nebraska, for example, is currently adding about 2,000/yr. In some areas, the increased deployment could affect the local water table. Both the University of Nebraska and the EROS program used LANDSAT images experimentally to count the number of center pivots in use during the irrigation season. The number of center pivots in part of Holt County, Nebr., for example, increased from 508 in July 1972 to 555 in July 1973 and 740 in August 1974.

Wetlands inventory using LANDSAT data

The Remote Sensing Institute of South Dakota State University (R. G. Best, D. G. Moore, and Robert Lindler (South Dakota State Univ.), 1974) employed LANDSAT data to inventory the wetlands of Codington County, S. Dak. The locations, spatial distributions, areal extents, and vegetative cover types were determined for the county, which is typical of the Prairie Potholes region of the northern Great Plains. Changes in the number of wetlands and their areas were determined between April 25, 1973, and October 4, 1973. The investigation indicated that LANDSAT data can be used to measure the effects of land changes on wildlife.

Analyses were made by optical processing techniques in which enlargements of the original images to scales as great as 1:60,000 were prepared. At this scale, recognition of open-water wetlands by photointerpretation was effective for areas as small as stockponds for certain landscapes. Vegetation classification and recognition of vegetation-filled wetlands were limited to areas of approximately 4 ha or larger. A light snow cover on the landscape made it easier to interpret and map the occurrence of emergent vegetation within wetlands. Areas larger than 24 ha were measured with errors of less than 10 percent with an inexpensive compensating planimeter.

LANDSAT imagery aids ground-water exploration

G. K. Moore and Morris Deutsch (1975) investigated applications of LANDSAT imagery to ground-water investigations. The imagery offers an opportunity to apply satellite data to nationwide water-resource studies, since it can be used both as a tool and as a form of basic data. Its main advantage is its reduction of the need for field work. Broad regional features, which are difficult or impossible to see on the ground, can be seen easily on LANDSAT images. Some present and potential uses indicated from examinations of satellite data are as follows: (1) Location of ground water indicated by phreatophytes growing along the Rio Grande River east of Los Alamos; (2) delineation of areas of recharge by means of playas in the southern High Plains of Texas; (3) improvement of aquifer development and management by delineating urban sprawl and growth in the Chicago area; (4) improved delineation of landforms and geologic structures in Missouri, New York, and Pennsylvania; and (5) delineation of water-bearing faults and joints in Tennessee.

LANDSAT data useful for surface-water mapping

The Remote Sensing Institute of South Dakota State University developed optical processing techniques for enhancing LANDSAT data as a source of surface-water information, including areal extent and the presence of suspended sediments, algae, and emergent vegetation (D. G. Moore, M. E. Wehde, and V. I. Myers (South Dakota State Univ.), 1974). Black-and-white prints of the several MSS bands were differentially exposed to depict contrasting tones in water and comparatively interpreted by using both multispectral and temporal approaches. Enlargements were registered to USGS topographic maps at scales as large as 1:62,500, and lakes as small as 2.4 ha were planimetered. For color composites of multispectral data from LANDSAT, bands 4, 5, and 6, instead of the customary combination of bands 4, 5, and 7, were used to produce maximum contrast within the water. MSS band 7 provides the greatest contrast for locating surface-water boundaries but yields relatively little information on water characteristics.

EASTERN REGION

Flood mapping from space

Morris Deutsch and F. H. Ruggles, Jr. (USGS), together with George Rabchevsky (Photo Science, Inc.) (Deutsch, Ruggles, and Rabchevsky, 1974; Deutsch and Ruggles, 1974), analyzed LANDSAT data covering the floods that occurred during 1973 on the Mississippi and Connecticut Rivers in the United States and the Indus River in Pakistan. They determined that areas in flood can be quantitatively determined by optical data-processing techniques. They also observed that the effects of flooding on the reflectance characteristics of the surface make it possible to delineate areas from which floodwaters have receded by using postflood data; this procedure eliminates the necessity for (1) continuous tracking with images of the flood crest and (2) reduction of the volume of data required. Interpretations of flood conditions as well as delineation of floodwater boundaries were made from color composites of MSS near-infrared bands 6 and 7. A flood wave of July 1973 on the Connecticut River was projected onto a 1:24,000-scale USGS topographic map by using an MSS band-7 image. The flood boundary was accurately delineated, as determined by field checks and comparison with conventionally acquired data. For the Indus River flood, spectrally enhanced images were used not only to delineate flooded area but also to reveal areas of ponded water, leakage under a dam, canal breaks, regional hydrologic conditions, and flood-plain details.

FOREIGN AREAS

Remote sensing in Iceland

During a long-term, binational, multidisciplinary remote-sensing research project conducted by the USGS and various Icelandic scientific organizations, LANDSAT imagery in particular, as well as NOAA imagery, color and color-infrared aerial photography, and aerial thermography (thermal infrared imagery), was used to study various dynamic environmental phenomena of Iceland; primary emphasis was placed on Icelandic geothermal areas, volcanoes, glaciers, and rangeland areas (R. S. Williams, Jr., and others, 1973a, b).

Of particular scientific importance was the study of the area encompassed by Icelandic glaciers and icecaps. Initial analysis of the available LANDSAT-1 images has shown the importance of repetitive imagery for:

1. Recording relatively short term glaciological changes. According to measurements made on two LANDSAT-1 images taken 11 mo apart, an outlet glacier in the northeastern part of Vatnajökull surged 1.8 km. A combination of field observations and LANDSAT image analysis showed a total surge in excess of 3 km, which probably took place in a few months, perhaps in as little as a few weeks. Contorted moraines on another of Vatnajökull's outlet glaciers, Skeidarárjökull, on the southeastern coast, showed a movement of 600 m in 11 mo, even though the snout of the glacier remained in essentially the same position.

   Several glacier-margin lakes were observed to change in size during the year (1972–73), particularly Grænalón, which enlarged each time that it was imaged until its size diminished markedly after a jökulhlaup partially emptied the lake in August 1973. Seasonal changes in the size of sediment plumes along the coast, where glacial rivers debouch their sediment-laden water into the ocean, were observed in a time-lapse manner (Williams and others, 1974).
2. Furnishing the data necessary to revise certain glaciological features on maps and to produce orthoimage maps of icecaps directly from LANDSAT images at map scales of 1:250,000. Sufficient LANDSAT images of Iceland from the late summer and early fall of 1973 now exist to planimetrically map accurately the 90 percent of Iceland that is covered by glacial ice. The best possible images (minimum snow cover, maximum exposure of glacial ice) have been obtained of Vatnajökull, Langjökull, Hofsjökull, Mýrdalsjökull, and Eyjafjallajökull, or five of the seven largest icecaps in Iceland and five of the smaller (less than 50 km^2) icecaps as well. On August 19, 1973, Hofsjökull had an area of 915 km^2 on LANDSAT images. Its area has usually been cited as 996 km^2. On a 1945 Danish Geodetic Institute map (1:500,000 scale), the area is 981 km^2; 1969 U.S. Army maps (1:250,000 scale) show an area of 943 km^2 (Williams and others, 1975).
3. Mapping subglacial volcanic and structural features. Within or at the margins of the icecaps and outlet glaciers, a number of new glaciological, structural, and volcanic features can be mapped from LANDSAT-1 images, particularly at low solar illumination angles (<10°); these features include several probable subglacial central volcanoes, calderas, and tectonic lineaments. Some of the effects of jökulhlaups can be mapped, including subsidence cauldrons resulting from subglacial volcanic activity or intense geothermal activity (R. S. Williams, Jr., and Sigurdur Thorarinsson, 1973; Thorarinsson and others, 1973; Williams and others, 1973c).

LANDSAT imagery aids hydrogeologic mapping in North Yemen

LANDSAT imagery was selected to support a study of the hydrogeology of North Yemen. Optical enhancements of the images reveal details of alluvial fans and coastal plain sediments that will significantly reduce the time needed for field observations and improve hydrogeologic mapping accuracy. Structural controls on the movement of ground water were readily observed by M. J. Grolier and Morris Deutsch. Whereas sand dunes in the northeastern part of the country could not be delineated on unenhanced LANDSAT images, the enhanced images revealed the dune distribution in detail and, in some areas, the distribution of subdunal bedrock.

Applications of LANDSAT data to land-system mapping in Australia

C. J. Robinove, working with coinvestigators in Queensland, Australia, studied the application of LANDSAT data to land-system mapping, a unique Australian approach to describing and mapping land capability, primarily for agricultural purposes. Digital computer analysis of LANDSAT-image magnetic tapes is a promising tool for classifying and mapping land systems and may supplement to a great degree normal photointerpretation and field-mapping procedures.

Ground-water exploration in Kenya

Morris Deutsch (1975) assessed the potential of remote-sensing techniques for ground-water exploration along the Tana River in Kenya. Anomalous vegetation distribution resulting from the presence of shallow ground water in an otherwise semiarid region was readily observed on low-altitude color-infrared images. Emitted radiation measurements taken from the low-flying aircraft with a precision radiation thermometer showed an inverse relation-

ship between infrared transmittance of vegetation and the radiometric temperatures.

Application of LANDSAT data to mineral exploration in South America

A followup experiment to evaluate LANDSAT multispectral imagery as a tool in exploring for mineral resources in the Andes Mountains of South America was conducted by W. D. Carter in cooperation with geologists from Peru, Bolivia, Chile, and Argentina. Emphasis was placed on the use of seasonal data to determine how time-variant phenomena (sun angle, soil moisture, snow distribution, vegetation) aid or hamper the recognition of areas where mineral resources are likely to occur. The association of prominent linear features with the distribution of known deposits and mapped fault zones was established by earlier work. CCT's from the LANDSAT MSS system were analyzed on an interactive computer analysis system. Reflectance signatures for known rock outcrop areas (the copper-bearing Totora Formation and freshwater limestone) have been extended throughout a scene covering 34,225 km^2. Future work of this type will attempt to develop signatures for alteration zones associated with major porphyry copper deposits of northern Chile and to subdivide the salt deposits of major salars such as Uyuni and Coipasa in Bolivia.

REMOTE-SENSING EXPERIMENTS BY OTHER BUREAUS

The EROS program continued to support investigations conducted by other Bureaus to assess the utility of remote sensing in resource inventory. A summary of the progress of these experiments follows.

Monitoring weather parameters for the High Plains Cooperative Program

A. M. Kahan (Bureau of Reclamation) developed and tested an automatic system, using LANDSAT DCS capabilities, for the collection of precipitation and meteorological parameters from the Bureau's High Plains Cooperative Program cloud-seeding site near Miles City, Mont. The design incorporates a network of digital precipitation gages, developed as a part of this program, operating within a 19-km radius of a LANDSAT DCP station. The design also includes a concept for data collection by aircraft from a network of gages operating over an area of several thousand square kilometres. These prototype networks were installed near Miles City for the summer operating season.

Colorado River natural-resource and land-use data acquisition

R. L. Hansen (Bureau of Reclamation) worked with the University of California at Berkeley to transfer the university's computer software systems to the computer system at the Bureau's Engineering and Research Center in Denver, Colo. Bureau personnel were assisted in making the necessary modifications to the software. Trained Bureau personnel will do complete analyses of LANDSAT images from CCT's for agricultural inventory as it relates to use of irrigation water. Cooperative efforts with the university will continue through calendar year 1976 to fully develop the Bureau's in-house capability for digital analysis of remote-sensing data, not only for agricultural inventory but also for a variety of natural resources. This technology should lead to better development and management techniques for water resources in the arid West.

Use of LANDSAT data in fishery management

J. B. Reynolds (U.S. Fish and Wildlife Service) utilized LANDSAT imagery as a resource management tool for solving fishery management problems in Midwestern States. Methodologies for conducting inventories of small impoundments were developed through the use of LANDSAT imagery and ground-truth data provided by an interagency working forum composed of investigators from eight States. Accurate inventories of small impoundments are required for the allocation of fishery management efforts, extension activities, and distribution of hatchery fish.

Comparative analyses were made of inventory information previously gathered by the States and information derived from LANDSAT and aircraft imagery. Reynolds feels that computer analysis of LANDSAT images will provide more rapid inventories of key areas within the Midwestern States.

LUMINESCENCE STUDIES

The Fraunhofer line discriminator (FLD) is an electro-optical device that operates as a nonimaging radiometer and permits detection of solar-stimulated luminescence several orders of magnitude below the intensity detectable by the human eye. R. D. Watson and W. R. Hemphill reported that airborne tests of the FLD permitted measurement of significant differences in the luminescence of trees growing in soils containing geochemically high concentrations of cop-

per (near Denver, Colo.) and molybdenum (near Reno, Nev.) and that of trees growing in background areas nearby. In other airborne tests, the FLD distinguished luminescing phosphate rock from gypsum and barren sandstone near Pine Mountain, Calif.; dispersal of oil in a natural seep from uncontaminated seawater in the Santa Barbara Channel in California; sewage effluents near Denver; and paper-mill and phosphate-processing effluents in eastern and central Florida.

Supporting measurements made by using a fluorescence spectrometer demonstrated the technique of predicting in the laboratory the optimum FLD wavelength required to detect the luminescence of a material prior to mounting an airborne test. Luminescence spectra were measured for each material and corrected for wavelength variation in source and detector sensitivity, and the results were compared to the luminescence of a dilute standard solution of rhodamine WT dye. The luminescence of each material was then related to the FLD, which has a sensitivity of 0.25 ppb rhodamine WT dye in ½ m of water. The optimum Fraunhofer wavelength for detecting metal-stressed vegetation with an FLD was found to be 656.3 nm; for each of the other materials, the wavelength was 486.1 nm.

Results of these laboratory measurements are as follows:

Material	*Luminescence expressed as rhodamine equivalent WT dye concentration (ppb)*
Oil seep	4.0
Metal-stressed vegetation	0.3–0.7
Phosphate rock	0.7
Phosphate-processing effluent	0.8–2.4
Paper-mill effluent	0.30–1.6

APPLICATIONS TO GEOLOGIC STUDIES

The radiobrightness of moist or frozen soil

The radiobrightness of soil is profoundly affected by the amount and state of included liquid water because the relative permittivity and loss tangent of liquid water are far greater than those of truly dry rock or soil. If the included moisture is frozen, however, the bulk dielectric properties approach those of the dry host material. A. W. England and G. R. Johnson reported that this characteristic can be used to remotely obtain the depth of a phase boundary (either frozen soil over moist soil or moist soil over frozen soil) from the spectral character of the radiobrightness. That is, the energy at appropriately short wavelengths originates within the layer, whereas energy at relatively longer wavelengths originates within both the layer and the underlying half-space. The resulting variation with wavelength of the radiometric temperature is interpretable in terms of layer thickness. Theoretical models of the effect are consistent with observations at 21 cm.

It is possible, therefore, to remotely sense a thermal anomaly that affects the thickness of seasonally frozen ground. It should also be possible to remotely observe the rate of melting of an active layer over permafrost and to infer moisture content.

Mineral-resource studies using LANDSAT images

A technique that combines digital computer processing and color compositing was developed by L. C. Rowan and P. H. Wetlaufer (USGS), A. F. H. Goetz and F. C. Billingsley (Jet Propulsion Laboratory), and J. H. Stewart (USGS) (1974) for enhancing subtle spectral reflectivity differences among exposed rock and soil units. This technique has been used to detect and map hydrothermally altered areas and to distinguish among many rock types in a LANDSAT–1 MSS image of a part of south-central Nevada. Field evaluation shows that altered areas appear as anomalous color patterns on the color-ratio composite and that these areas agree very closely with those mapped on the ground. Most of the distinctions realized through this approach cannot be obtained by using MSS color-infrared composite images or Skylab/EREP color images.

Landform analysis using LANDSAT–1 MSS images and image mosaics of Nevada showed that linear features compiled without respect to length have approximately 25 percent coincidence with mapped faults. However, the major lineaments (>10 km in length) and the mapped faults have about 80 percent coincidence, and substantial extension of locally mapped faults is commonly indicated. Seven major lineament systems identified by Rowan and Wetlaufer (1975) appear to be old zones of crustal weakness that have served as preferred conduits for rising magma through periodic reactivation. Reactivation of these zones approximately 30 m.y. ago led to migration of silicic volcanism from the central basin to a crudely circular feature 150 km in diameter, the central Nevada volcanic complex. The horizontal and vertical extents of this feature are substantiated by aeromagnetic, gravity, and seismic refraction data. Known metal mining districts are concentrated along five of these major lineament systems. However, the central Nevada volcanic complex occupies an area of low productivity, which is probably due to burial of

older deposits by a thick sequence of silicic volcanic rocks deposited between 30 and 19 m.y. ago.

Lineaments in South Carolina and the Mississippi Embayment

In a LANDSAT study by T. W. Offield of the Atlantic Coastal Plain of South Carolina, long, straight drainage lines were the dominant lineaments; these trend northwest, parallel to and commonly coinciding with alinements transverse to the general trend in the magnetic basement, and possibly mark the positions of Triassic dikes. All but 2 of 22 crudely located historic epicenters in South Carolina lie along topographic drainage lineaments, and most are near lineament intersections.

Lineaments mapped by D. W. O'Leary and S. G. Simpson from LANDSAT images of the northern Mississippi Embayment generally showed groupings of several orthogonal sets, which varied somewhat in trends and intensity of development from one geomorphic-tectonic province to another. The dominant lineament group trends N. 40°–50° E. throughout the region, regardless of local tectonic setting, only slightly skew from the location of microearthquake activity. A second major lineament trend, N. 40°–50° W., approximates a subsidiary trend in the seismic data.

Near-infrared reflectance anomalies of andesite and basalt

High-reflectivity anomalies in the near infrared (1.0 to 2.6 μm) were observed by H. A. Pohn on scanner images obtained by the Environmental Research Institute of Michigan on flights over southern California and southwestern Nevada and, more recently, on all three Skylab missions. These anomalies almost always occur in andesites or more mafic rocks. Laboratory spectra obtained from the rocks collected in the anomalous areas show that some rocks exhibit the highest reflectivity from their natural surfaces, whereas others show a distinctly higher reflectivity from cut surfaces. In the last case, the material (as yet unknown) giving rise to the anomalous reflectivity seems to have been emplaced at the same time that the host rocks were deposited and to have been altered at the surface by weathering. If this occurrence is common enough and if its cause can be determined, the intensity of the anomaly might be used as a relative age-dating factor for volcanic materials.

Principal lineament systems seen in orbital images reflect ancient major breaks in basement rocks

Lineaments, fractures, and faults mapped by D. P. Elston at a 1:24,000 scale correlate with lineaments and lineament systems mapped from orbital images. The major lineament systems mapped for central Arizona occur in sets of orthogonal pairs that closely correspond to the principal directions of fracturing and folding in Precambrian rocks of the Grand Canyon of northern Arizona. The principal lineament systems trend northeast and north, can be traced across parts of the Colorado Plateau in rocks that are only a few million years old, and reflect throughgoing fracture systems in the Precambrian basement. Paleomagnetic orientations of the principal fault and lineament systems (1,700, 1,100, and 850 m.y. ago) describe a general clockwise rotation through about 220° of arc. Senses of displacement on the fault systems as they rotated through time to the present suggest that most compressive stresses originated from a westerly (Pacific) direction and that most normal faults stepped down to the east.

Detection of geothermal areas from Skylab thermal data

Skylab–4 S–192 X–5 thermal data from The Geysers, Calif., area were analyzed by H. A. Pohn to determine the feasibility of using midday Skylab images to detect geothermal areas. The hottest ground areas indicated on the Skylab image corresponded to south-facing barren or sparsely vegetated slopes. Thermal well No. 4, a geothermal area approximately 15×30 m, coincided with one of the hottest areas indicated by Skylab. However, this area could not be unambiguously distinguished from the other areas, which are believed to be hotter than their surroundings as a result of topography and micrometeorological conditions. A simple modification of a thermal model (Watson, 1971) was made, and the predicted temperatures for the hottest slopes were in good agreement with the observed data. It is concluded that data from a single midday Skylab pass cannot be used to locate geothermal areas.

Characterization of surface roughness in Death Valley, California

The conclusions of the Death Valley radar study conducted by G. G. Schaber are summarized as follows:

1. Small-scale roughness of natural sedimentary surfaces can be distinguished and measured by means of long-wavelength SLAR image data obtained at high antenna depression angles.
2. The radii of curvature of surface irregularities responsible for an observed breakpoint between weak and strong diffused backscatter (within the Rayleigh region of scatter) are restricted to a size range of between 0.08 λ and 0.14 λ. At

the 25-cm wavelength, the range is between 2 and 3.5 cm.

3. The breakpoint on the Rayleigh region of the backscatter function can be predicted by using a model of Rayleigh backscattering from an array of spheres on a plane. A plot of the radar cross section, normalized to the resolution element area, shows that, at a radius of curvature of 0.01 λ, an inflection occurs in the curve. The agreement of the theoretical model and the field observations suggests that even single-frequency SLAR systems, when properly calibrated for return power, can be useful tools for geologic mapping.
4. Antenna depression angles restricted to between 45° and 90° appear to optimize the image data for surface backscatter evaluation by providing more return power and by eliminating extensive radar shadowing effects.

APPLICATIONS TO HYDROLOGIC STUDIES

Remote sensing used successfully in two hydrologic studies in Alabama

J. G. Newton, in cooperation with the Geological Survey of Alabama, used photography, thermal imagery, and radar as supportive tools for a variety of water-resource investigations. There were two significant results.

1. Color-infrared photography was the primary tool used in locating one of the highest yielding wells in Alabama. The well, which taps limestone, is near Centreville, in an area where previous test drilling failed to locate satisfactory supplies. It has been pumped at a rate exceeding 63 l/s, with a drawdown in water level of less than 1 m. The well was located at the intersection of a lineament and a line of previously unmapped sinkholes. The lineament was formed on sands and clays of Cretaceous age that rest on limestone of Paleozoic age. It extends more than 8 km from an area near the limestone outcrop to an area in which large springs discharge. The lineament is formed largely by the alinement of surface drainage and accompanying variations in vegetation. It is parallel to the strike of Paleozoic strata and probably reflects faulting or post-Cretaceous solution of the underlying purer carbonate strata (W. M. Warren and C. C. Wielchowsky, 1973).
2. Color-infrared and black-and-white-infrared photography were utilized in Shelby County to define linear trends formed by active sinkhole development. These trends defined areas most prone to sinkhole development and the location of one fault. The photography, used in conjunction with photography taken in 1960, also helped to determine the relationship between collapses in an area of large water withdrawals and construction. In one small area containing 33 recent collapses, 26 collapses (79 percent) were located where timber had been removed or were within 15 m of a highway, its drain, and a gas pipeline.

Icing surveys along the TAPS corridor

LANDSAT images, high- and low-altitude aerial photographs, thermal-infrared images from an airborne scanner, and photographs taken with a hand-held camera from light aircraft were used by C. E. Sloan to map the location and extent of icings along the TAPS corridor. Large icings, also called "aufeis," occur in wide braided channels of major streams along the route. Small-channel and hillside icings are common in geologic terrane that has the capacity for shallow ground-water storage. Both surface- and ground-water sources feed and sustain the growth of icings. Ground disturbance in permafrost terrane tends to aggravate the icing problems. Icings, where they overtop roads, may cause flooding and erosion and impair traffic flow.

Determining lake depth on the Alaskan North Slope with SLAR

SLAR images of the North Slope of Alaska between Barrow and Harrison Bay, obtained by the USGS Mohawk remote-sensing aircraft in April and May 1974, were used to study the tundra lakes in that region. According to W. J. Campbell, the SLAR images indicate that the tundra lakes can be separated into two classes based on the strength of the returns. Correlations between the areal patterns of the returns, limited ground observations of lake depths, and the information obtained from LANDSAT images strongly suggest that freshwater lakes giving weak returns are completely frozen, whereas lakes giving strong returns are not. Brackish lakes also give weak returns even when they are not completely frozen, presumably because the brine present in the lower portion of the ice cover limits the penetration of x-band radiation into the ice. The physical cause for the differences in radar backscatter has not been determined. The ability to separate tundra

lakes rapidly and easily into two classes by using SLAR images will be useful in many ways, including the determination of the annual dependable water supply for a given lake.

Effect of dual-wavelength excitation on Raman scattering intensities

Recent use of the anti-Stokes lines to examine hydrogen plasmas suggested the use of a dual-wavelength excitation to enhance Raman signal intensities. Several calculations were made by M. C. Goldberg and J. R. Riter, Jr., who used known Raman cross sections to investigate the limits of this effect against a water background. Particular attention was given to maintaining all variables at reasonable values and examining the lower limits of the number of scatterers in solution to determine detection sensitivities for solutes in dilute aqueous solutions. The dual-wavelength technique suffers from a large amount of water signal, and the calculations indicate that minimum detection levels are 1,000 mg/l for solutes similar to the nitrate ion.

Remote-sensing techniques applied to hydrologic problems in Florida

A. E. Coker and A. L. Higer (A. E. Coker, A. L. Higer, R. H. Rogers, N. J. Shah, Lawrence Reed, and Sylvia Walker, 1975) compared wavelengths from Skylab and LANDSAT scanners to determine their adaptability to land-water classification. The longer wavelength bands on Skylab's S–192 scanner were found to enhance land-water features.

A. L. Higer, A. E. Coker, and E. H. Cordes (1974) reported that the USGS acquisition network using LANDSAT data is a viable approach for obtaining the near-real-time data needed to solve hydrologic problems. Selected water-quantity and water-quality data obtained from ground stations are transmitted through LANDSAT to NASA receiving stations. This data relay has been reliable, and, by coupling ground information with LANDSAT images, a modeling technique is available for water-resource management in southern Florida.

Land use and vegetation in the Green Swamp, Florida

Using Skylab MSS data, A. E. Coker categorized the land-water cover types of the Green Swamp area of central Florida. The categories are shown on a color-coded computer-generated thematic map of the swamp area.

The Green Swamp, the fountainhead of five rivers, is a broad, flat wetland comprising about 2,250 km^2 of the central highlands of the Florida Peninsula. The swamp was chosen as a Skylab/EREP test site; data were from the June 13, 1973, NASA/Skylab pass No. 10. A. E. Coker, A. L. Higer, R. H. Rogers, N. J. Shah, Lawrence Reed, and Sylvia Walker (1974) reported that automatic mapping with MSS data produced a nine-category land-water cover map.

A map series report of land-water categories in the Green Swamp was prepared by Coker, B. F. McPherson, and Higer. The categories represent selected vegetation composites and land-use practices and were derived by computer processing of Skylab MSS data as part of a NASA/EREP study of the area. A map that depicts wetlands and intermittently wet and well-drained uplands should be helpful for estimating drainage conditions for land-use planning in the Green Swamp area.

Remote sensing used in Minnesota water-resource investigations

To determine the usefulness of remote sensing in water-resource investigations in Minnesota, G. F. Lindholm and R. F. Norvitch evaluated Skylab, LANDSAT, and NASA high-altitude images and photographs in selected areas. Analyses include image-enhancement techniques made possible by using special equipment at the EROS Data Center near Sioux Falls, S. Dak. Results indicate that photographs taken in the spring (May) are best for delineating areas of surficial sand. Sand areas are best defined on LANDSAT color composites or Skylab color-infrared photographs. The repetitive coverage of LANDSAT demonstrates temporal changes in the areal extent of the Snake River during the peak-runoff period of 1973. The effects of changing ground-water levels on features visible on high-altitude photographs are not readily apparent on images made in 1973 when both spring and fall recharge were well below normal.

Image enhancement for hydrologic studies

Results of experiments conducted by G. K. Moore showed that composite viewing of LANDSAT images may enhance the determination of both the lithology and the geologic structure in the southeastern United States. In the first series of experiments, LANDSAT images made during different seasons of the year were reproduced on high-contrast film and combined on a color-additive viewer. A sharp boundary (marking the edge of hydrologically significant thicknesses of sand and gravel) along the Cretaceous and Paleozoic contact in northwestern Alabama was defined by differences in tone, texture, and drainage patterns. None of these factors is apparent on any single LANDSAT scene.

In the second series of experiments, composite viewing (with a mirror stereoscope) of LANDSAT images made on different dates showed many more lineaments than could be seen on any single LANDSAT scene.

LANDSAT images used to improve estimates of streamflow characteristics

LANDSAT images were used by E. F. Hollyday to discriminate the physiographic characteristics of drainage basins in an effort to improve equations used to estimate streamflow characteristics at ungaged sites.

Records of 20 gaged basins on the Delmarva Peninsula of Delaware, Maryland, and Virginia were analyzed for 43 statistical characteristics of streamflow. Hollyday formulated multiple-regression equations that related these characteristics to basin characteristics. Physiographic characteristics obtained only from maps and images were used in a control group of equations. Characteristics from images were forest land, riparian vegetation, water, and combined agricultural and urban land. These characteristics were separated photographically by using film-density-discrimination techniques. The area of each characteristic in each basin was measured photometrically.

Comparison of control-group equations with experimental-group equations revealed that 15 out of 40 equations were improved (standard error of estimate reduced by more than 10 percent). For example, the equation for the 5-yr-recurrence flood peak was improved by 32 percent; the mean monthly streamflow equation for September was improved by 25 percent; the 7-d 2-yr-recurrence low-flow equation was improved by 20 percent; and the 3-d 2-yr-recurrence flood-volume equation was improved by 60 percent. It was concluded that using data from LANDSAT images can significantly improve the equations, and therefore the estimates, for some streamflow characteristics at ungaged sites on the Delmarva Peninsula. The potential exists for improving estimates in other physiographic regions.

Snow measurements from LANDSAT images

A snow-covered area was measured from LANDSAT images by M. F. Meier (USGS) and W. E. Evans (Stanford Research Institute). Two mountain massifs and 16 drainage basins were measured on images made on many dates during two melt seasons. It was determined that snow cover can be monitored by using LANDSAT images—assuming that clouds and a closed forest canopy do not interfere—and that some satisfactory results are possible when only single-band radiance slicing is used; however, more precise determinations require two-band ratioing or other more complicated pattern-recognition techniques. Areal values in drainage basins can be used to calculate the equivalent snowline altitude, which has value for extrapolation to other nearby basins that may be cloud covered or appear only partially on images.

Applications of remote-sensing techniques to the study of seasonal snow cover

Results of studies by M. F. Meier (1973, 1974) showed that the areal extent of snow can be measured by means of manual, optical, electronic, or digital techniques from data supplied by visible and near-visible light sensors carried on Earth-resource and meteorological satellites. These techniques cannot routinely detect snow under clouds or a forest canopy. Active or passive microwave systems may permit such detection over large areas, but the physics of these possible techniques is not yet sufficiently understood. The wetness or the temperature of a snow surface can be measured by thermal-infrared radiometers; wetness throughout a snowpack can be measured by microwave radiometers. The electromagnetic scattering properties of snow have not been defined.

APPLICATIONS TO CARTOGRAPHIC STUDIES

During fiscal year 1975, the Topographic Division was funded by NASA and the EROS program of the Department of the Interior to investigate specific cartographic applications of space imagery and high-altitude photography. The principal emphasis was placed on data from LANDSAT–1 and LANDSAT–2, with secondary emphasis on Skylab missions SL–2 through SL–4.

LANDSAT investigations for cartographic application began with the first LANDSAT launch in 1972, were augmented by data from the second launch in early 1975, and resulted in recommendations to NASA concerning specifications for LANDSAT–C, scheduled for launch in 1977. Skylab was launched early in fiscal year 1974, and experiments continued with data from the S–190A, S–190B, and S–192 sensors.

Satellite-image maps

Prototype image maps were prepared from LANDSAT and Skylab images at scales ranging from 1:125,000 to 1:1,000,000 and in standard and experimental formats. Some maps were produced in several versions—monochromatic, sepia tone, and multicolor, with varying cartographic enhancement.

The Florida satellite-image mosaic is the product of innovative procedures combining computational photogrammetry, image geometric control, photomechanical mosaicking, and color lithography. Florida presented a new set of cartographic problems, since it extends across seven LANDSAT orbits, two basically different vegetation patterns, and two UTM zones. The assembly of 17 images was controlled photogrammetrically by using 27 points scaled from 1:24,000-scale topographic maps as ground control. The mosaics were prepared by contact printing through precise exposure windows onto high-resolution stable-base film. The MSS band-5 mosaic was used to prepare both the magenta and yellow plates, and the MSS band-7 mosaic, the cyan plate. This two-band three-color printing process yielded an image that closely resembles the usual false-color (infrared color film) rendition. A fitted UTM grid (computed from ground control points) and the text were overprinted in black. The accuracy of well-defined points measured from the grid on the printed map is estimated at 200 m. All the individual image-format maps of Florida are being prepared as a by-product of the mosaic; four covering southern Florida at 1:500,000 scale are in press. Black-and-white 1:250,000-scale standard-format satellite-image mosaics are being prepared from the Florida band-5 mosaic.

The second version of the 1:500,000-scale satellite-image map of Arizona was published. In contrast to the first version, which was simply a black-and-white gridded image mosaic, this map is a sepia-tone image overprinted with blue water features and a black UTM grid, selected culture, and text. A similar sepia edition of the 1:250,000-scale Phoenix image map also shows red roadfill.

Two black-and-white photomaps of the State of Connecticut are being prepared, one from S–190A panchromatic photographs formatted to the 1:250,000-scale Hartford topographic map and the other from S–190B color and color-infrared photographs formatted to the 1:125,000-scale Connecticut State base map.

Marking LANDSAT images with solar reflectors

On October 1, 1974, in collaboration with W. E. Evans (Stanford Research Institute), the USGS succeeded in marking a LANDSAT–1 MSS image with three mirrors positioned at the National Center in Reston, Va. The mirrors—one slightly convex and two plane—were oriented to reflect the Sun's rays to the satellite and thus generated cones of light of 0.5° (the angular diameter of the Sun as seen from the Earth). The plane mirrors produced two bright spots on the image, and the convex mirror produced a less visible spot. The mirror flashes registered as high radiometric response levels—2 to 5 times those of adjacent pixels (the smallest element recorded by the scanner)—on the digital tape readout. After the October experiment, various types of mirror support and methods of pointing were tested. On November 24, LANDSAT–1 was flashed with a plane mirror oriented by an autocollimation technique using a Wild T2 theodolite and computer-generated data. As before, the response in bands 4, 5, 6, and 7 reached the saturation level for the mirror-site pixel.

This marking technique will have little cartographic application in the United States (with the possible exception of Alaska) because the country is relatively well mapped, and suitable LANDSAT-identifiable features can be described to an accuracy better than the sensor pixel (about 79×79 m or 1 acre). In poorly mapped areas lacking identifiable points, the technique does have cartographic potential for marking such features as offshore oil rigs, small islands, or poorly defined points in Antarctica or the Amazon Basin. If points are geodetically located, they would then be located with respect to all other features imaged by LANDSAT in the same area, and thus the utility of the geodetic control would be extended.

Digital processing of LANDSAT images

Mead Technology Laboratories (Dayton, Ohio), under contract to USGS, is investigating the feasibility of enhancing the photographic quality of LANDSAT MSS images by digitally processing and combining successive images of the same Earth scene. CCT's of MSS images from five passes over Phoenix and five passes over upper Chesapeake Bay are being digitally processed and correlated and converted to hard copy for comparison with the hard copy produced from a single MSS pass. If the quality of LANDSAT imagery can be improved by digital techniques, the scope of cartographic and other applications could be expanded.

Cartographic evaluation of LANDSAT

From the mapping viewpoint, LANDSAT exceeded expectations. The results of LANDSAT–1 cartographic experiments, conducted by USGS and other foreign and domestic mapping and charting agencies, justified a resource satellite program that should continue for a decade. The comprehensive cartographic evaluation continued with the objective of defining requirements and specifications for an operational LANDSAT-type satellite based on worldwide cartographic needs.

To date, the following applications of LANDSAT-type imagery are considered feasible:

1. Serving as an image base for photomapping at scales of 1:250,000 and smaller and in a variety of formats.
2. Aeronautical charting, both for revision of gross features on line charts and as an image base for selective thematic mapping.
3. Mapping of shallow sea areas.
4. Extending control from mapped areas into and across unmapped areas.
5. Identifying artificial points by marking images with a small mirror.
6. Automated correlation to the figure of the Earth.
7. Revising gross features on line maps at scales of 1:250,000 and smaller.
8. Thematic mapping of water, infrared-reflective vegetation, snow and ice, collective works of man in some areas, and spatial changes in these themes.
9. Precise delineations of waterlines at various stages.

Future evaluations will be based on the development of a variety of LANDSAT cartographic products and applications of various scales, waveband treatments, formats, and processing techniques. Product utility and potential economic value will be determined through sales analysis and specific response from those applying LANDSAT imagery cartographically.

Specifications for LANDSAT–C

General requirements and specifications for LANDSAT–C were recommended by the EROS program on behalf of the Department of the Interior. The recommendations, which were based on input from most of the Department's concerned user agencies, Canadian and Australian mapping agencies, and the World Bank, were evaluated and combined by the EROS Cartography Coordinator. Further study was suggested on such options as the wavelength of band 4, variable gain settings, and range of the thermal channel.

APPLICATIONS TO GEOGRAPHIC STUDIES

Phoenix and southern Arizona land-use mapping project

The final report on the NASA-sponsored test of the utility of LANDSAT film imagery in updating a land-use map of the Phoenix, Ariz., 1:250,000-scale quadrangle, which had been previously compiled from high-altitude aerial photographs, was completed and accepted by NASA (Place, 1974). This investigation showed that the satellite color-composite transparencies could aid in the interpretation of land use and complement the high-altitude aerial photography in monitoring seasonal changes of vegetation and water bodies.

Central Atlantic Regional Ecological Test Site (CARETS) project

The CARETS project, jointly sponsored by NASA and the USGS, continued to analyze the usefulness of remote sensors as sources of land-use and land-cover data for input to a regional environmental information system. This system is based on the flow of land-use and related environmental data through several stages, from acquisition by remote-sensing techniques to users, and involves user evaluations and feedback. The basic assumption of the CARETS project is that there is a measurable environmental impact associated with land use and land-use change as determined with remote-sensor data, and, therefore, such data sets can be used to provide regional planners and other users with an understanding of the environmental changes occurring in their areas.

The CARETS research involves three interrelated subtasks:

1. Land-use analysis: An analysis of the accuracy of the CARETS land-use maps was completed for a 1-percent sample of the test-site area. Maps using level II of the USGS land-use–land-cover classification, produced at three scales (1:24,000, 1:100,000, and 1:250,000) from high-altitude aircraft photographs, were compared with one another and with other data obtained by field surveys. The same procedures were employed to determine the accuracy of the level I land-use maps produced at a 1:250,000 scale from high-altitude aircraft photographs and LANDSAT images. By simple comparison of point data samples from maps with field-survey data, the accuracy of the

level II maps was determined to be 84.6 percent at a 1:24,000 scale, 76.8 percent at 1:100,000 scale, and 73.0 percent at a 1:250,000 scale. Part of the difference in accuracy is attributed to increasing generalization of data when they are mapped at smaller scales. However, accuracy computations differ for different major land-use categories, and a simple percentage calculation of the correspondence between sample points and field data is not considered to be a fully adequate statement of accuracy for land-use maps. The accuracy of the level I 1:250,000-scale maps was 76.6 percent from aircraft photographs and 71.8 percent from LANDSAT images.

2. Environmental impact assessment: A series of related investigations to evaluate and assess the impact of land-use patterns and changes on the environment continued. H. P. Guy and E. J. Pluhowski experimented with using level I and II land-use data derived from LANDSAT and aerial photography sources to evaluate the effectiveness of CARETS land-use data in improving estimates of streamflow characteristics in selected Maryland drainage basins. Of 40 streamflow characteristics tested, 7 showed more than 10 percent improvement (reduction of the standard error) in prediction equations, and 2 showed more than 10 percent impairment in the predictions. Improvements were possible because of the information on the amounts of urban, forest, and agricultural land in the drainage basins.

   J. E. Lewis, S. I. Outcalt, and R. W. Pease investigated the usefulness of aerial and satellite thermal imagery combined with land-use data in simulating the urban climate. The most recent research along these lines was an experiment using thermal data from the Skylab satellite as an input to an urban climate model.

   A regional environmental study was conducted for Virginia Beach, Va. It was determined that environmental problems such as barrier-beach stabilization, beach replenishment, and sewage disposal resulted from decisions based on faulty knowledge of the coastal and wetland ecosystems that are vital to the city.

   Further environmentally related research involved the use of remote sensing to identify the causes of manmade ground-water pollution. Results indicate that certain remote-sensing data sets are useful in identifying land-use types that have ground-water pollution potential associated with them.

3. User evaluation: The user interaction and evaluation phase of the CARETS project was set up to obtain the assistance of local, regional, State, and Federal agency users of land-resource information in designing an experimental regional information system. The evaluation revealed that many user agencies at all levels of government require data more detailed than those provided by the CARETS project. Few agencies found the generalized LANDSAT level I land-use–land-cover maps useful. Although the level II data were considered valuable by several users, most found them to be of secondary utility to their needs. The products considered most useful were the high-altitude color-infrared photographs and the USGS orthophotoquads.

   The digitization of CARETS land-use–land-cover data by the Canadian Geographic Information System progressed in several stages. The 1:250,000-scale level I land-use–land-cover maps prepared from LANDSAT images were digitized, and computer-printed land-use area summaries, by county, were completed for the entire CARETS area.

   A separately funded research effort, contained within the CARETS framework, was an evaluation of the Skylab S–190B Earth terrain camera. A 1:24,000-scale land-use map of Fairfax, Va., was produced from Skylab photographic data and compared with a 1:24,000-scale field-corrected land-use map prepared from high-altitude aircraft photographs. Both maps utilized level III land-use categories. By means of a point sampling technique, the relative accuracy of the Skylab map was determined to be approximately 83 percent.

Comparative urban studies

Another aspect of geographic applications research and analysis dealt with comparative land-use studies of a selected sample of U.S. urban areas using data received from remote sensors aboard high-altitude aircraft and satellites. Land-use maps and statistical summaries were prepared by manual photographic interpretation and area analysis techniques for Boston, Mass.; New Haven, Conn.; Cedar Rapids, Iowa; Phoenix and Tucson, Ariz.; and Pontiac, Mich.

Products for all these demonstration areas (except Boston and New Haven) included maps of land-use changes for the period 1970–72, tabulations of land areas and changes by land-use category, and census tracts. Summaries by urban area for 1970–72 were prepared for most of the test sites. Researchers applied observable land-use boundary segments equivalent to the intent of the U.S. Bureau of the Census urbanized-areas definition so that urban-area changes in the intercensual period could be monitored by remote-sensing techniques.

Land-use data acquired from Skylab images made over some of these demonstration areas were compared with data from aerial photographs and ground surveys. Results of this comparison show that uses of satellite imagery and (or) conventional sources of data depend upon the aim and needs of the user. Extensive briefings and discussion were held with user groups to acquaint them with the applications and limitations of the various experimental products.

Under a contract with the Association of American Geographers, the USGS completed two tasks in supportive research in 1975. One of these was an analysis of Washington, D.C., land-use data derived from airborne remote sensors in order to construct and test an urban spatial model and to relate land-use changes during 1970–72 to an urban growth model.

The second task—the preparation of a guide to assist users of remote-sensing data with land-use mapping and inventory—resulted in the completion of a publication (Wiedel and Kleckner, 1974) that is essentially a description of analytical tasks and alternatives primarily in the use of airborne remote-sensing data. The publication illustrates options in the uses of these data and cites examples from various Geography Program research projects.

Meanwhile, research continued in learning about and applying ways to generate land-cover information and to monitor land-use changes by direct computer-aided interpretation of multitemporal and multispectral data acquired from LANDSAT. One applications thrust was to gather and analyze land-cover information for comparative urban regional studies, compare the data with information acquired by conventional means, and assess general applications benefits and costs.

Another thrust sought to demonstrate specifically the feasibility of using computer-processed satellite data to complement inputs required for the USGS Land-Use Data and Analysis (LUDA) program, which is primarily dependent on manual compilation from higher resolution source materials. Results are incomplete but are showing the capabilities and limitations of the different approaches. This research, therefore, suggests ways not only to exploit the complementary features for the LUDA program but also to identify other applications of monitoring data acquired in digital form from satellite platforms.

LAND USE AND ENVIRONMENTAL IMPACT

RESOURCE AND LAND INVESTIGATIONS PROGRAM

The RALI program established the following short-term tasks to be implemented in fiscal year 1975:

1. Identify and assess the utility to the State and local planning community of selected data and information products (such as maps), systems (such as geographic data systems), and sources. This activity concentrated initially on programs of the USGS and subsequently on those of other Department of the Interior Bureaus and Offices. Its purpose is to develop the ability to knowledgeably advise State and local planners on the availability, sources, extent of coverage, uses, and limitations of data.
2. Develop and disseminate information products, including a series of directories of data holdings and special information products of the Department of the Interior.
3. Identify technical expertise in the Department that is required by the regional, State, and local planning community and develop procedures to make appropriate personnel available for consultation.
4. Continue to support and coordinate the preparation of methodological guidebooks that will improve the state of the art in resource management methods and techniques and further the proper application of existing methods and techniques in areas of interest to the Department.

COUNCIL OF STATE GOVERNMENTS TASK FORCE

The National Symposium on Resource and Land Information initiated a 1-yr study of State land-use programs and policies by the Task Force on Natural Resource and Land Use Information and Technology. The symposium brought together approximately 200 persons representing the executive and legislative branches of State government, Federal agencies, interest groups, and other organizations.

The task force was sponsored by the Council of State Governments under a grant from the RALI program and in cooperation with the Office of Land Use and Water Planning of the Department of the Interior. A series of background papers on land-use policy and program analysis was published in late 1974 and 1975 (Task Force on Natural Resources and Land Use Information and Technology, 1974a–e, 1975a–c).

The task force report describes the difficulties involved in land planning and management in terms that permit better evaluation by political institutions. The task force examined State experience and evaluated the options available to States in establishing or strengthening land-management programs. It also reevaluated the Federal role in land management and provided a State perspective for future Federal legislation.

PRODUCT EVALUATION PROJECT

The purpose of this project was to design and demonstrate a process of feedback between selected State land and natural-resource data users and the RALI program. Specifically, the aim was to have the Council of State Governments, as an intermediary third party, canvass State data users to determine (1) how much use they can make of selected federally prepared data products, (2) what use they are currently making of natural-resource data, and (3) the best means for continuing a product evaluation feedback mechanism that would facilitate communication between State users and Federal data producers.

Samples of natural-resource data products considered by their producers to be new and innovative were obtained from various Federal agencies; these were largely map products. Criteria devised to evaluate each product were presented as questions to users in seven States. The States were chosen largely on the basis of the States' involvement in the particular program areas.

The user responses to the particular products reviewed in this project and other results of discus-

sions with State program officials indicate, in some areas, a significant consensus as to what is needed by State data users. For example, among the most frequently used or required items are USGS 7½-min topographic quadrangles, USDA Soil Conservation Service detailed soil surveys, high-resolution aerial photography, information on the location and quantity of surface water and ground water, and recent land-use–land-cover data.

ENVIRONMENTAL ASSESSMENT WITH APPLICATION TO WESTERN COAL DEVELOPMENT

RALI has recognized the need for making a comprehensive analysis of the potential impacts associated with the development of Western coal resources and in particular for making the information available in useful form to the planning community. During fiscal year 1975, RALI's efforts to meet these requirements have taken the form of two investigations, each of which has resulted in published reports.

The purpose of the first study was to describe the type of commercial activities that might be expected in the development of Western coal reserves. Coal mining is the primary activity and is likely to be accompanied by the development of means to transport coal from mining areas to centers of consumption. Slurry pipelines and unit trains are examined for the transportation of coal over significant distances. Alternatives considered to transporting coal out of the region include the local conversion of coal to synthetic fuels or electric power, the production of substitute natural gas by coal gasification, and the generation of power at the mine location. Descriptions of these alternatives are given by Anthony Bisselle and others (1975).

The second investigation was directed toward the development of a systematic way to forecast "higher order" impacts, as distinct from direct or "primary" air, water, and land effects. Higher order impacts are long-term consequences on the physical, social, and economic conditions in a region, caused by repercussions along the web formed by the network of cause and effect events.

To determine the present state of the art and to aid development of analytical methodology, an annotated bibliography of techniques was prepared and published by G. Bennington and others (1974).

The methodology develqped in this research entails combining a series of primary environmental impacts expected as a result of future activities with a matrix of environmental impact relationships. Each term in this matrix relates a change in one cause in one year to a change in effect the following year. Thus, the forecasts for each of a set of environmental activities are produced that consider both direct and higher order impacts.

This research is described by Benjamin Schlesinger and Douglas Daetz (1975).

LAND-USE DATA AND ANALYSIS PROGRAM AND OTHER GEOGRAPHIC STUDIES

The Land-Use Data and Analysis (LUDA) program was initiated late in 1974 to provide a systematic and comprehensive collection and analysis of land-use and land-cover data on a nationwide basis. The initial nationwide collection of these data will be completed within a 5-yr period. Periodc revision of these data is planned.

LUDA maps are being compiled at a scale of approximately 1:125,000. For each land-use–land-cover map produced, overlays are also compiled showing Federal land ownership, hydrologic units, counties, and census county subdivisions. State land ownership is shown when such information is made available by the appropriate State agency. These overlays are keyed to the standard topographic map series at 1:250,000 scale. By June 1975, 1,100,000 km² of land-use–land-cover data were compiled, and 128 quadrangles were in production. The compilation of these map sets is being accomplished through regional mapping centers of the Topographic Division with specifications, quality control, and accuracy checks to insure standardization and with consultation on program development provided by the Geography Program.

A series of tests was conducted by the Geography Program to determine the most effective means of assessing the accuracy of maps prepared under the LUDA program. A combination of two methods proved to be the most efficient means. Low-altitude aerial photography and ground-traverse data are used to identify problem areas observed by interpreters as well as to provide a systematic check on general interpretations throughout the map area. Land-use–land-cover data are compiled at a scale of 1:125,000 and then reduced and keyed to the combined black and blue color-separation plates of the standard 1:250,000 topographic sheets. The minimum mapping unit for urban and built-up uses, water areas, confined feeding operations, other agricultural land, and strip mines, quarries, and gravel pits is 4 ha. All other categories are delineated with a mini-

mum unit of 16 ha. Federal land holdings are shown for tracts of 16 ha or larger.

Land-use and land-cover data are digitized in a polygon format. Conversion of land-use polygons to land-use grid cells of varying sizes can be made when desired.

There are three stages of release of maps and data:

1. Maps are available on open file in USGS libraries and may be reproduced upon request, at a nominal cost, on ozalid paper, ozalifoil, semistable ozalid, cronar, or cronaflex materials. The standard land-use–land-cover maps and accompanying overlays showing counties, hydrologic units, Federal land ownership, and census county subdivisions are available at a scale of 1:250,000. These products can also be obtained upon request at scales within a reasonable range of the compilation scale of approximately 1:125,000. For example, under a cooperative agreement with the State of Florida, land-use–land-cover maps were supplied at a scale of 1:126,720 to match the scale of county highway maps in common use in that State.
2. Computer-generated maps and statistical data are made available upon request about 6 mo after land-use–land-cover maps and accompanying overlays have been made available as indicated above. Magnetic tapes are also available for sale as well as documented software needed for the use of the computer-generated data. Of course, computer-generated maps can be supplied at any scale compatible with the original compilation scale of approximately 1:125,000. It would be inappropriate, however, to use land-use–land-cover data compiled at 1:125,000 for preparing maps at scales such as 1:24,000, 1:50,000, or 1:1,000,000.
3. Lithographed maps are to be published in color.

Because of the dynamics of land use, the emphasis in the preparation and distribution of all products will be on supplying information to the users in the shortest possible time. Applied research in data and information requirements, inventory methods, and data use, as well as interpretative studies, are also being carried out under the LUDA program in order to supply to State and Federal planners, resource managers, and other users a basis for the most efficient and effective use of these land-use–land-cover data.

LUDA map and data uses in Louisiana

Louisiana was among the first States to be completely mapped under the nationwide LUDA mapping program. Louisiana officials promptly used these data, along with satellite images of the State, to determine how many hectares of various types of land were inundated by spring floods during 1975.

A computerized analysis completed within 2 weeks of peak flooding and 4 d after the last satellite picture was taken showed that 440,000 ha of Louisiana were flooded at the highest stages on the Mississippi, Red, Ouachita, Black, and Atchafalaya Rivers.

By comparing the LUDA land-use maps with flood-time LANDSAT images, State officials determined that floodwaters covered approximately 3,200 ha of urban and other highly developed regions, 120,000 ha of farmlands, 43,600 ha of upland forests, 279,200 ha of wetland forests, and 1,120 ha of sand and silt deposits. Aided by the LUDA computerized data and a computer program specialist from the Geography Program, the Louisiana Office of State Planning staff broke down these totals for each parish (county) that had been flooded.

This effort marked the first time that land-use and land-cover maps and data were used to give a State Governor prompt, detailed information on how many hectares of each land-use type, by county or other area, had been affected by flooding.

Selected experimental LUDA demonstration projects

In the State of Georgia, a land-use map of the Atlantic metropolitan region was prepared at a scale of 1:100,000 for use by the State Geologist's Office. The land-use map overlays the regional topographic map at the same scale. The LUDA land-use–land-cover information is used in conjunction with existing data such as those on mineral resources, soils, seismicity, nuclear-reactor-site location, and ground water already available to the State Geologist's Office.

Land-use maps at 1:24,000 were also produced for selected portions of the 1:100,000 map of the Atlanta area. For planning and demonstration purposes, a complete county and the entire Peachtree Creek drainage area were mapped at this larger scale.

The Atlanta Regional Commission used these LUDA data for planning activities within the eight-county region. The standard LUDA data were augmented by information on urban parkland and institutional areas and a further breakdown of hydrologic units compiled by the commission.

Environmental impact uses of LUDA data

A land-use–land-cover map was prepared for the region being studied by the Interagency Task Force on Development of Phosphate Resources in Southeastern Idaho. This 1:100,000-scale map enabled the task force to relate environmental impact problems to population distribution and other patterns of human and natural resources. Large-scale land-use maps were compiled for the Soda Springs area as an aid in assessing the effect of increasing population pressures on urban development and community services. These maps will be included in the final environmental impact statement released by the task force.

Land-use–land-cover classification system

The land-use–land-cover classification system proposed by the USGS after many meetings and consultations with representatives of Federal and State agencies is resource oriented. In developing such a land-use–land-cover data system, several basic assumptions, needs and requirements were recognized:

1. Recognition of existing, frequently used categories of land use and land cover. Sophisticated but unfamiliar terminology was carefully avoided, although a more refined or detailed approach to the classification of land use and land cover might be more acceptable to those seeking to institute a classification system that relies more on logic than on practicality.
2. Flexibility in using the proposed approach to standardization at the more generalized levels of classification.
3. Application of an available and rapidly expanding array of remote-sensor technology.
4. Recognition of the need for a means of quantifying the use and character of land-use–land-cover data on a consistent repetitive basis.
5. The assignment of a single use or cover designation to a given area so that a multiplicity of uses could be handled by using the overlay method rather than by using combinations of use and cover categories.

The revision of USGS Circular 671 (J. R. Anderson, E. E. Hardy, J. T. Roach, and R. E. Witmer, in press) will have "land cover" added to its title to indicate more clearly the intermixing of land-use and land-cover terminology in the classification system. To some, this intermixture is undesirable. However, a careful evaluation of alternatives led to the conclusion that unfamiliar or infrequently used terms would be introduced if strict adherence to one terminology or the other was observed. This approach to land-use–land-cover mapping permits the aggregation of level II categories into level I categories. Even more important, it allows level III land-use–land-cover categories to be added as desired by users. Such categories would represent further subdivision of the level II land-use–land-cover categories already compiled.

For example, under a cooperative agreement with the State of Florida, land-use and land-cover data are being compiled at level II. At the request of the Florida State Department of Planning, an overlay of selected level III categories is being prepared. Some of the level III categories being overlaid and fitted to the level II categorization are (1) citrus groves separated from other groves, nurseries, and so forth, (2) mangrove swamps and cypress bogs separated out of the level II "forested wetland" category, and (3) mudflats separated out of nonforested wetland.

Cooperative land-use data projects

A cooperative agreement between the Ozarks Regional Commission and the USGS to provide land-use–land-cover maps and data for portions of the Ozarks region was completed in 1974. During 1975, amendments 1, 2, and 3 were completed. Work completed under the agreement was used as a basis for the development of the LUDA program.

Amendment 1 extended land-use mapping and data coverage to all areas of the State of Arkansas that had not been previously covered. A complete land-use–land-cover data base for Arkansas is now available in graphic format and with computer-assisted analysis capability for land-use studies within the State. The data base contains land-use information delineated in compliance with level II land-use–land-cover categories, political boundaries, public land ownership, and drainage areas. The Arkansas Highway Department used these data for highway corridor planning.

Amendment 2 provided for compilation of additional data for those counties bordering the Arkansas River from its junction with the Mississippi River to Tulsa, Okla. These data consist of overlays keyed to the standard 1:250,000-scale maps and show the 100-yr-old flood-plain outline, mineral deposits, utility lines, surface transportation, fish and wildlife areas, and historic sites. The Arkansas River Development Corporation used these data in combination with a previous study to determine land-use changes within a selected area along the Arkansas River.

Amendment 3 provided for the digitizing of land-use–land-cover data covering a four-county area in

central Arkansas. Data from a soils-capability map were combined with the flood-plain, mineral-deposit, and fish and wildlife data from the Arkansas River project to provide nine levels of resource information to be used in statistical data development for Faulkner, Perry, Pulaski, and Saline Counties.

A final report, prepared jointly by the Ozarks Regional Commission and the USGS Geography Program, describing the research and experimental work involved in the land-use–land-cover mapping and data project was published and distributed by the Ozarks Regional Commission at Little Rock, Ark. (Loelkes and McCullough, 1975).

Land-use maps and statistical data for Louisiana were completed to fulfill a cooperative agreement between the State of Louisiana and the USGS. These data include land use, land ownership (Federal and State), river basins, State and county boundaries, and census tract enumeration districts and were mapped at a scale of 1:250,000. These data were also digitized and already have been used for delineating flooded areas during the spring of 1975. The land-use–land-cover maps and data were supplied to the Louisiana Office of State Planning at Baton Rouge to complete the terms of this cooperative agreement.

Similar land-use maps were prepared at a scale of 1:50,000 for Lycoming County and the six counties in the Pittsburgh, Pa., area (Allegheny, Armstrong, Beaver, Butler, Washington, and Westmoreland Counties).

Geographic information system development

The Geography Program carried out research and development work on a geographic information system to provide the capability for computer-aided storage, editing, manipulation, and retrieval of a geographic data base for the LUDA program and other land-use–land-cover research projects of the USGS. The system includes: (1) Digitization of maps of land-use–land-cover and other environmental data, (2) editing and updating of the geographic data base, and (3) manipulation and retrieval of those data in order to perform area measurements, map-compositing analysis, and statistical and other computer-aided operations.

Routine digitizing, editing, and correction of land-use and land-cover overlays for all of the State of Louisiana and part of the State of Florida were completed in cooperation with the Johns Hopkins Applied Physics Laboratory and by using the Geography Program's Graphic Input Procedure (GIP). A preliminary version of documentation for the GIP was completed and supplied to planning groups in Louisiana and Florida for use in their own computer facilities.

Digitization of LUDA products with a laser scanner began under a contract with the I/O Metrics Corporation.

The procurement and implementation of the Advanced Interactive Digitization (DIGIT) system and the CART/8 computer-aided map-compilation system were completed in January 1975. These systems are being utilized as an alternative procedure for the operational digitizing, editing, and correction of land-use and land-cover maps prepared for the LUDA program and other Geography Program research projects.

A grant made to the IGU's Commission on Geographical Data Sensing and Processing for advice and guidance on problems relating to the development of a geographic information system in the USGS was completed. The draft of the final report included an examination of selected geographic information systems in the United States and Canada and a description and analysis of five spatial-data encoding techniques.

An additional grant to the IGU commission, concluded in June 1975, for the review and analysis of the LUDA/USGS data base development provided for (1) determining the status of data base-structure development in the USGS, (2) evaluating the applicability of existing software for computer-aided spatial-data manipulation, data management, data analysis, and computer-aided mapping and graphics, and (3) analyzing CART/8 and the Information for Management After Graphic Evaluation (IMAGE) capabilities for use in the USGS Geography Program.

ENVIRONMENTAL IMPACT STUDIES

The Environmental Impact Analysis (EIA) program was officially established within the Land Information Analysis office on April 10, 1975. The EIA program provides direction, coordination, and expertise in the preparation of environmental impact statements (EIS) for which the USGS is the lead or joint agency and provides technical information and expertise in support of the preparation of EIS' to which the USGS is only a contributor. The EIA program provides technical analysis, review, and comment on EIS' prepared by other agencies and stimulates, promotes, and conducts environmental research related to the work and anticipated needs of the program.

ANALYSIS OF ENVIRONMENTAL IMPACT STATEMENTS

Some environmental research studies are involved with analyzing the areas of environmental concern and the problems of collecting, integrating, and presenting environmental data. These analyses provide the basis for guidebooks designed to assist the EIA program, and other organizations with similar responsibilities, in the preparation and review of EIS' and for suggesting topical investigations and research needed to formulate and implement policies for the USGS and the Department of the Interior.

During fiscal year 1975, the EIA program reviewed approximately 2,100 EIS' prepared by other agencies. On the basis of a sampling of 1,400 EIS', the subject matter of these reviews breaks down approximately as follows:

Subject of EIS	*Percentage*
Road construction	29
Hydrologic projects	26
Airport construction	10
Building construction	8
National forest management	7
Nuclear power	4
Wilderness proposals	4
National park management	3
Sewage-treatment facilities	3
Utility-line installation	2
Others	4
Total	100

Energy-related EIS' account for 13 percent of the reviews received but require 20 percent of the total review time. EIS' that are primarily concerned with mineral resources account for 4 percent of both the number of reviews received and the time required for their processing. Because construction projects make use of crushed rock, sand, and gravel, these natural resources are of secondary concern in approximately 75 percent of the EIS' reviewed.

On the basis of an analysis of these 1,400 EIS' with geologic implications, 4 percent are considered outstanding in that they present enough pertinent, detailed geologic information to permit the reader to make an independent evaluation of the impact of a proposed action. Treatment of geologic elements is more or less adequate in 56 percent of the statements and clearly inadequate in 20 percent, which fail to describe geologic conditions adequately enough to support even a crude assessment of environmental impact. Geology is ignored in 20 percent of the EIS' reviewed. This analysis indicates a need for a greater awareness of the significance of geology in planning not only for the extraction of minerals or mineral fuels but also for the emplacement of the many types of engineering structures that produce major alterations of the adjacent physical, economic, and cultural environments. The EIA program is instigating needed guidance in the form of technical assistance, training sessions, and guidebooks for both governmental organizations preparing EIS' and private organizations assembling data required for an environmental impact analysis.

ENVIRONMENTAL IMPACT RESEARCH

Other environmental research studies are concerned with delineating the thresholds at which EIS' are required, determining which aspects of the environment are important or critical to environmental impacts, and evaluating techniques for analyzing the potential impacts as well as monitoring the actual impacts of various actions reported in EIS' and assessing them, especially in terms of land-use decisionmaking.

W. J. Schneider, task force leader for the Southeastern Idaho Phosphate Resources EIS, reported that land-use maps of that area are being prepared at compilation scales of 1:125,000 and 1:24,000 to provide visual support for the EIS being prepared for that area. Prestripping and current land-use patterns are being delineated to provide a basis for assessing the impact of stripping on land use. Continuing strip-mining activity will be monitored by remote sensing supported by ground checking, as required.

Ancillary research such as trace-element analysis of slag, soil, water, and air contamination associated with mining or ore processing is currently supported by the Federal Interagency Task Force on Southeastern Idaho Phosphate Resources.

INTERNATIONAL COOPERATION IN THE EARTH SCIENCES

With the development of new concepts and techniques in the Earth sciences, the growth of scientific capability in developing countries, and changes in the U.S. foreign assistance program, the emphasis of the USGS's continuing program of cooperation with other countries changed from largely technical assistance to cooperative research and scientific exchange. In the past, a large part of the work was done under the auspices of the AID (Department of State) and its predecessor agencies, whereas an increasing number of projects are now sponsored by, and funded by, the cooperating country or through international organizations. AID continues to sponsor some selected projects of the USGS.

The USGS international program can be broken down into four major categories: (1) Technical assistance to strengthen Earth-resource institutions and programs in developing countries; (2) scientific and technical cooperation on subjects of mutual concern; (3) participation in international commissions and programs; and (4) response to natural disaster.

TECHNICAL ASSISTANCE AND COOPERATION

The year 1974 was a period of significant development and change in the USGS's international program. Three long-continued projects (Brazil, Colombia, and Indonesia) were substantially completed; extensions into 1975 were made only on a limited basis to permit completion of reports and previously scheduled activities. In Brazil, USGS scientists were given short-term assignments during the first part of 1975 for demonstration and training in hydrologic and geologic subjects, and Brazilian participants continued to visit the United States for supplementary instruction, as requested by the Government of Brazil. In past years, the program included: (1) Exploration and appraisal of a wide variety of minerals, including uranium and the well-known iron deposits of the Quadrilatero Ferrifero; (2) hydrologic investigations; (3) education projects in Earth sciences and techniques; (4) remote sensing; (5) geochemistry; (6) geophysics; and (7) advisory services designed to strengthen the Brazilian Earth-science institutions. In Colombia, assistance to the National Institute for Geology and Minerals was terminated during the first part of 1975. The Colombian program, which ran from 1963 to 1975, consisted largely of assistance in mineral exploration and geologic mapping, training in Earth sciences, and institutional development. The 5-yr Indonesian project was terminated by P. W. Richards and R. W. Schaff in early 1975. The project accomplished its stated objective of assisting the Geological Survey of Indonesia in improving its systematic geologic mapping capabilities and its capacity to identify, map, and evaluate mineral and other geologic resources.

During 1974, new cooperative programs were initiated in Bolivia and Yemen. The USGS and the Bolivian Ministry of Mines and Metallurgy signed a Memorandum of Understanding covering a 5-yr period; under the terms of this agreement, the USGS will provide reimbursable technical assistance to appropriate Bolivian agencies to help strengthen, enlarge, and intensify their mineral exploration and development activities. The first projects under this Memorandum of Understanding involve assistance in initiating a mineral exploration fund and establishing a computerized data bank for mines and mineral deposits.

Under an agreement with Yemen sponsored by AID, the USGS began a 3-yr investigation of groundwater and mineral possibilities in the northern part of the country using conventional geologic techniques and LANDSAT–1 satellite data. Objectives are to provide information useful for the development of water and mineral resources and to lay the groundwork for further study by the Yemeni Government, as well as to train Yemeni scientists and technicians so that they can continue this work in the future.

In response to a request by the Algerian Ministry of Hydraulics, the USGS entered into discussions concerning a program to provide technical assistance to the Ministry in training Algerian personnel in the techniques of remote sensing and to develop a facility for processing remote-sensing data.

The long-range Saudi Arabian project, scheduled to end in 1975, was extended to 1978, and the USGS program in Thailand continued under the direction of J. O. Morgan. The USGS was also involved in a cooperative program with Mexico, discussed below.

Personnel of the USGS participated in a number of Earth-science activities of the Central Treaty Organization (CENTO) during 1974. T. P. Thayer and N. J Page took part in field studies of ophiolites and the mineral deposits associated with them in Turkey and Pakistan. R. P. Sharp served as the U.S. participant at a meeting of the Working Group on Recent Tectonics held in Quetta, Pakistan. J. B. Cathcart, D. F. Davidson, R. A. Gulbrandsen, and J. W. Mytton led field excursions in the northwestern and southwestern phosphate fields of the United States; 10 scientists from CENTO regional countries and the United Kingdom also participated. Also, E. H. Bailey again participated in the summer field-training course in applied mining geology for students from the CENTO countries. These courses have been given since 1966, and, thus far, 119 geologists and mining engineers have received training.

The second and third International Training Courses on Remote Sensing were held from May 30 to June 28 and September 19 to October 12, 1974, respectively, at the EROS Data Center in Sioux Falls, S. Dak. The courses were part of a cooperative program developed by AID and the USGS to provide training for scientists and engineers of developing countries. The purpose of the courses was to train participants in (1) the practical applications of LANDSAT satellite imagery and (2) the types of aerial remote-sensing data that might be readily available to them.

At the earlier course in the spring, 34 scientists from 21 nations attended, and, in the fall, 20 scientists were present from 11 nations.

S. J. Gawarecki, J. O. Morgan, and C. J. Robinove participated as consultants in remote sensing at the Seminar on the Application of Remote-Sensing Technology to Natural Resources Development held in Bangkok, Thailand. The 1-week seminar was sponsored by the Economic and Social Commission for Asia and the Pacific, a United Nations organization. Eighty-three participants from 20 countries and 5 specialized agencies and intergovernmental bodies attended.

Following the seminar, Gawarecki and Morgan participated as instructors in the 3-week Mekong Coordinating Committee Training Course and Workshop on Application of ERTS Data to the Development of the Mekong River Basin. The course was attended by eight trainees, two each from Thailand, the Khmer Republic, Laos, and Vietnam. After the seminar, Robinove went to Australia, where he presented five 2-d courses and one 1-d course in remote sensing, with emphasis on LANDSAT data, in Sidney, Melbourne, Adelaide, Perth, and Brisbane. The lecture circuit was sponsored by the Australian Government.

The USGS and various other U.S. Federal agencies are participating in joint technical cooperation agreements that have been or are being executed between the United States and several Middle Eastern countries. In Saudi Arabia, the USGS is presently helping to plan specific water-resource development projects and a national water-resource assessment. Discussions have been held concerning cooperation with Iran and Egypt.

Under a Memorandum of Understanding between the United States and the United Nations, the USGS provides consultation and advisory services in support of the Coordinating Committee for Joint Prospecting of Mineral Resources in Asian Offshore Areas (CCOP), a nine-nation committee supported by the U.N. Development Program. These services include the assignment of a marine geology consultant, Frank Wang of the CCOP secretariat staff in Bangkok, to assist in planning, conducting, and coordinating regional projects sponsored by CCOP. These include a major program of research on the tectonic development of the continental margin of Southeast Asia in which the CCOP countries are participating in cooperation with the Intragovernmental Oceanographic Commission and the U.S. NSF. The USGS also provides consultation to CCOP in analyzing satellite imagery to support this research.

USGS participation in cooperative scientific investigations with other countries under the Department of Interior's Special Foreign Currency Program (SFCP) continued during the year. Ongoing projects in Yugoslavia include investigations of techniques for mapping permeability in karst areas, seismic investigations of deep crustal structure, problems of earthquake reconstruction, and investigations of rare metals associated with alkalic plutons. In Poland, projects in 1974 included studies in mining hydrology and investigations of base-metal deposits in carbonate rocks. Two new SFCP projects were proposed for Poland: studies of the geochemistry of coal and of the comparative geology of coal basins. Three have been proposed for India: applications of remote sensing and geophysical techniques to the search for ground water and to the search for ore deposits and studies of the seismicity of the Himilayan front.

In support of the U.S. Antarctic Research Program (USARP) sponsored by the NSF, the USGS is publishing various map series and cartographic products. Four maps in the 1:250,000-scale series, Mount Berlin, Grant Island, Cape Burks, and Hull Glacier of the Hobbs Coast-Marie Byrd Land area, were compiled and are scheduled for printing. A revised index, *Topographic Maps, Antarctica,* which shows all maps published in Antarctica by the USGS, is also scheduled for printing. Seventeen maps in the 1:250,000-scale series are in various phases of compilation. Work on these maps, which cover an area along the Marie Byrd Land Coast between the Jones Mountains and the Hobbs Coast, will continue during fiscal year 1976.

Under joint NSF-NASA funding, cartographic experiments with LANDSAT–1 imagery included revision of the 1:1,000,000-scale Ross Ice Shelf planning map along the shelf's front and updating of the 1:1,000,000-scale McMurdo Sound region map. Both maps are in final stages of compilation. The McMurdo Sound region map will be the first map of Antarctica that conforms to International Map of the World specifications.

A single LANDSAT scene of the Ross Island, McMurdo Sound, and southern Victoria Land-Dry Valley areas was enlarged to scales of 1:250,000 and 1:500,000. Control was identified on the compilation image, and a fitted grid was printed on the final products, which await publication. This experimental product was developed to determine what uses and demands could be made of similar single-scene products within the polar scientific and logistic community. In further support of investigations on cartographic experiments, LANDSAT image maps and (or) mosaics of 14 coastal areas are being prepared at a 1:1,000,000 scale. A companion sketch map will also be available for those areas where LANDSAT images indicate significant coastal changes. The 14 LANDSAT image mosaics will be paneled into a LANDSAT image mosaic of the continent. The resulting product, at a 1:5,000,000 or 1:10,000,000 scale, will provide the first single photoimage mosaic of Antarctica.

Copies of all maps and cartographic products are made available to polar scientists associated with the USARP and to scientists of the 11 member nations represented on the Scientific Committee on Antarctic Research (SCAR). To date, 77 1:250,000-scale topographic maps covering about 820,000 km^2 have been published by USGS and distributed to SCAR.

As part of the USGS technical assistance and cooperation programs abroad, 150 Earth scientists and engineers from 38 countries pursued academic or intern experience in the United States during fiscal year 1975. Types of assistance to, or exchange of scientific experience with, each country during the fiscal year are summarized in table 3. Under USGS guidance, 1,542 participants from 95 countries had completed research, observation, academic, or intertraining programs in the United States as of June 1975.

Since the beginning of the technical assistance work in 1940, more than 2,214 technical and administrative documents authored by USGS personnel have been issued. During calendar year 1974, 98 administrative and (or) technical documents were prepared, and 94 reports or maps were published or released in open files. (See table 4.)

TABLE 3.—*Technical assistance to other countries provided by the USGS during fiscal year 1975*

Country	USGS personnel assigned to other countries			Scientists from other countries trained in United States	
	Number	Type	Type of activity [1]	Number	Field of training
Latin America					
Argentina	2	Geologist	D	--	
	3	Hydrologist	D	--	
	1	Structural engineer	D	--	
Bolivia	2	Geologist	C	--	
	1	Hydrologist	D	--	
	1	Structural engineer	D	--	
Brazil	1	Chemist	A	12	Minerals exploration.
	1	Geochemist	A	1	Economic, structural, and regional geology.
	15	Geologist	A, C, D	1	Hydrology, water-quality studies.
	1	Geophysicist	A	2	Remote sensing.
	6	Hydrologist	A, D	2	Geologic evaluation of mineral deposits.
				2	Computers: mineral resources.
				1	Airborne magnetometer techniques.
				6	Hydrology.
				1	Sedimentology.
				1	Geochemical exploration: granites.
				1	Evaporite deposits: exploration methods and interpretation.

TABLE 3.—*Technical assistance to other countries provided by the USGS during fiscal year 1975*—Continued

Country	USGS personnel assigned to other countries: Number	Type	Type of activity [1]	Scientists from other countries trained in United States: Number	Field of training
			Latin America—Continued		
Brazil—Continued				1	Analytical chemistry and atomic absorption techniques.
				1	Geochemistry.
				1	Geochemistry; mineralogy and petrology.
				3	Minerals drilling.
				1	Analytical techniques.
Chile	1	Geologist	A	--	
	1	Hydrologist	D	--	
	1	Structural engineer	D	--	
Colombia	1	Chemist	A	2	Seismic research observatories.
	11	Geologist	A, D	--	
	1	Samples expert	A	--	
	1	Structural engineer	D	--	
Costa Rica	2	Geologist	D	--	
	1	Geophysicist	D	--	
Ecuador	1	Structural engineer	D	1	Remote sensing.
				1	Hydrology.
Guatemala	1	Geologist	D	--	
Honduras	1	Geologist	D	--	
Mexico	1	Geologist	D	--	
	2	Hydrologist	D	--	
Nicaragua	1	Geologist	D	2	Earthquake hazard reduction.
	2	Geophysicist	A	1	Remote sensing.
Panama	1	Hydrologist	D	--	
Paraguay	1	Hydrologist	D	--	
Peru	5	Geologist	C, D	--	
	5	Geophysicist	C, D	--	
	1	Research civil engineer	D	--	
	1	Structural engineer	D	--	
Trinidad-Tobago	1	Structural engineer	D	1	Hydrology.
Venezuela	1	Geologist	D	--	
	1	Structural engineer	D	--	
			Africa		
Algeria	1	Civil engineer	D	--	
	2	Geologist	D	--	
	1	Hydrologist	D	--	
	1	Administrative officer		--	
Egypt	2	Geologist	D	--	
Ghana				1	Remote sensing.
Ivory Coast	2	Geologist	A	--	
Kenya	2	Hydrologist	B, C	6	Do.
				1	Hydrology.
Lesotho				1	Remote sensing.
Nigeria				1	Do.
Somalia	1	Research forester	D	--	
			Near East–South Asia		
Afghanistan				1	Remote sensing.
				2	Hydrology.
Bangladesh				1	Remote sensing.
India				1	Do.
				5	Hydrology.
				1	Exploration geology.
				1	Ground-water development.
				1	Hydrogeology.
				2	Borehole geophysics in hydrogeologic investigations.
				2	Water-quality studies.
				1	Atomic minerals exploration.
Iran	4	Geologist	C, D	4	Seismic research observatories.
				4	Remote sensing.
Israel				1	Operation of magnetic observation.
Jordan	1	Geologist	C, D	--	
Nepal	2	Hydrologist	A, B, C	3	Ground-water investigation and hydrology.
				1	Remote sensing.
				1	Hydrology.
				1	Ground-water investigation—water chemistry.
Oman	1	Geologist	D		

TABLE 3.—*Technical assistance to other countries provided by the USGS during fiscal year 1975*—Continued

Country	USGS personnel assigned to other countries: Number	Type	Type of activity[1]	Scientists from other countries trained in United States: Number	Field of training
Near East–South Asia—Continued					
Pakistan	1	Agricultural specialist	D	1	Atomic absorption spectrometry.
	3	Geologist	D	2	Remote sensing.
	1	Hydrologist	D	--	
	1	Physical scientist	D	--	
	1	Topographic engineer	D	--	
Saudi Arabia	4	Administrative officer		1	Computer applications.
	1	Cartographer	A, B	2	Computer electronics.
	1	Cartographic technician	A, B, D	--	
	2	Chemist	B	--	
	2	Computer specialist	B	--	
	3	Editor	A, D	--	
	6	Electronic specialist	A, B, C	--	
	2	General service officer		--	
	20	Geologist	A, B, C, D	--	
	2	Geophysicist	A, B, C	--	
	3	Hydrologist	D	--	
	1	Photographer	A	--	
	1	Topographic engineer	A	--	
Turkey	1	Geologist	D	7	Remote sensing.
				1	Cartography.
				1	Cartography—shaded relief.
				1	Analytical methods for geochemical exploration.
				1	Seismology.
				1	Sedimentology of carbonates.
Yemen	2	Hydrologist	A, B, C	--	
	2	Geologist	D	--	
Far East					
Burma				1	Field geology and geological mapping.
				1	Geochemistry.
China				2	Remote sensing.
				2	Seismology.
Indonesia	1	Cartographer	A, B, C	5	Remote sensing.
	8	Geologist	A, B, C, D	1	Publication of geologic maps.
	1	Publications specialist	D	1	Geological mapping.
Japan	2	Geologist	A, B, C	1	Sediment discharge and slope failure.
				1	Remote sensing.
Khmer Republic	1	Geologist	A, B, C	--	
Korea	3	Geologist	A, B, C, D	2	Remote sensing and interpretation.
Malaysia	1	Geologist	A, B, C	--	
New Zealand				1	Seismic research observatories.
Philippines	3	Geologist	A, B, C	1	Remote sensing.
				3	Hydrology.
Singapore	2	Geologist	A, B, C	--	
South Vietnam	2	Geologist	A, B, C	1	Remote sensing.
Taiwan	1	Geologist	A, B, C	--	
Thailand	7	Geologist	A, B, C	3	Do.
Western Samoa	1	Geologist	A	--	
Other					
Australia	1	Geologist	A	1	Remote sensing.
				2	Seismology.
				1	Research on geology of ore deposits; geochemical exploration.
Austria	1	Economist	D	--	
	3	Hydrologist	D	--	
	1	Physicist	D	--	
France	1	Geologist	D	1	Paleointensity determinations.
	2	Geophysicist	A, D	1	Photogeology—astrogeology.
	3	Hydrologist	A, D	--	
Germany	1	Hydrologist	A	1	Remote sensing.
Iceland				1	Radioactive logging.
Italy	2	Hydrologist	A	2	Remote sensing.
Netherlands				1	Geochemistry.
Norway				1	Remote sensing.
Poland	1	Hydrologist	A	--	
Romania				1	Mathematical modeling in hydrology.
Spain				1	Remote sensing.
				1	Water management.
				1	Hydrology.

TABLE 3.—*Technical assistance to other countries provided by the USGS during fiscal year 1975*—Continued

Country	USGS personnel assigned to other countries: Number	Type	Type of activity [1]	Scientists from other countries trained in United States: Number	Field of training
		Other—Continued			
Sweden	1	Hydrologist	A	--	
Switzerland	1	Hydrologist	D	--	
United Kingdom	2	Geologist	A, B, C	--	
	1	Geophysicist	D	--	
	1	Mining engineer	D	--	
	1	Physicist	A	--	
USSR	1	Hydrologist	D	--	
Yugoslavia	2	Geophysicist	D	1	Remote sensing.

[1] A, broad program of assistance in developing or strengthening Earth-science institutions and cadres; B, broad program of geologic mapping and appraisal of resources; C, special studies of geologic or hydrologic phenomena or resources; D, short-range advisory help on geologic or hydrologic problems and resources.

TABLE 4.—*Technical and administrative documents issued in calendar year 1974 as a result of USGS technical and scientific cooperative programs*

Country or region	Project administrative reports	Reports or maps prepared: Approved for publication by USGS or counterpart agencies	Published in technical journals	Published by USGS
Afghanistan	--	1	1	1
Africa	2	5	--	4
Algeria	1	--	--	--
Bangladesh	--	1	--	1
Brazil	1	13	--	10
Central America	--	1	--	--
Chile	--	--	--	3
Colombia	2	2	1	1
Costa Rica	2	1	--	--
Ethiopia	--	1	--	1
Indonesia	6	3	1	2
Jordan	--	2	--	2
Liberia	1	11	3	32
Libya	--	1	--	--
Nicaragua	--	2	--	--
Nigeria	--	--	--	1
Pakistan	--	1	--	3
Peru	--	--	--	1
Saudi Arabia	6	17	16	5
Spain	1	--	--	--
Thailand	5	2	1	--
Turkey	--	1	--	2
General	5	1	--	2
Total	32	66	23	71

INTERNATIONAL COMMISSIONS AND PROGRAMS

On behalf of the American Association of Petroleum Geologists, the CCOP, and the Pacific Science Association, the USGS is coordinating a multinational effort to compile geologic, tectonic, and resource maps of the Pacific region. This effort is called the Circum-Pacific Map Project. All countries in the Pacific region are collaborating, and participation has been organized in five panels—one panel for each of the four quadrants of the Pacific region and one for the Pacific-Antarctic region. J. A. Reinemund is serving as general chairman of the project. The project plans to compile geologic, tectonic, mineral, energy, and base maps of each of the four Pacific quadrants and of the Pacific-Antarctic region at a 1:10 million scale and tectonic and base maps of the entire Pacific area at a 1:20 million scale. The base maps are expected to be ready for publication this year, and the other maps in the succeeding 3 yr. The project is also attempting to develop computerized data banks of the information used in compiling the maps; this bank can be used in future revisions and updating of the maps and will be accessible to all participating countries.

A number of USGS scientists have been involved in the International Geological Correlation Program (IGCP), which is a joint activity of the IUGS and UNESCO. Reinemund is a member of the Board of the IGCP, and P. W. Guild is a member of one of the IGCP scientific committees. USGS scientists are coordinators for two approved IGCP Projects: P. C. Bateman for the project on circum-Pacific plutonism and A. L. Clark for the project on standards for computer applications in resource studies. In addition, E. H. Bailey, M. C. Blake, and R. G. Coleman participate in the project on ophiolites, R. B. Neuman in the project on the Caledonian orogen, and G. M. Richmond in the project on Quaternary glaciation.

In line with the USGS's primary responsibilities for the U.S. Federal geothermal exploration program, R. O. Fournier headed the U.S. Organizing Committee for the Second U.N. Symposium on Development and Use of Geothermal Resources held in San Francisco in May 1975. The symposium, sponsored jointly by the United Nations, the Department of the Interior, the State of California, and other public and private agencies, was the first such gathering to be held in the United States and was part

of an effort to foster international cooperation in developing new and alternative sources of energy. Approximately 1,000 attending geoscientists, including about 90 from the USGS, represented about 50 countries. Of the 130 papers delivered by representatives from 17 nations, about half were concerned with finding and evaluating sources of geothermal energy, and half dealt with uses of this resource and economic and legal problems. An abstract volume of 358 selected abstracts was published and available at the meeting.

The International Energy Agency, which was formed as a result of Secretary of State Henry Kissinger's Energy Conference of 1973, held its first meeting in 1974; C. D. Masters was the USGS representative. This organization, based in London, acts as a clearing house for data on coal resources and reserves gathered from 16 member nations. The data are sent to the USGS for inclusion in the World Resource Data System. Knowing the coal resources and reserves available will help the United States and other member countries to make realistic plans for coal utilization and to make current economic assessments of new sources of energy and of the impact of new technology on coal production. G. H. Wood, Jr., is the U.S. representative for the Interior Department and the USGS.

D. M. Kinney, vice president for North America for the Commission of the Geologic Map of the World, and P. W. Guild, president of the Subcommission for the Metallogenic Map of the World, attended the Commission's plenary session held in Paris in April 1974. Kinney reported on the progress of small-scale geologic mapping in North America in 1972–74. D. F. Davidson, delegate, and A. L. Clark, observer, represented the USGS at the COGEODATA (Committee on Storage, Automatic Processing, and Retrieval of Geologic Data) Biennial Meeting held in conjunction with the Map Commission meeting. COGEODATA is concerned with applying computer-based techniques to advance the science of geology.

Among the many other international commissions, conferences, and programs in which USGS scientists participated were the First Circum-Pacific Conference on Energy and Mineral Resources held in Honolulu, Hawaii, at which seven USGS members presented papers; the International Ophiolite Conference in Medellín, Colombia, attended by J. E. Case, R. G. Coleman, and M. R. Brock; and the Second Pan-Arab Mineral Conference in Jiddah, Saudi Arabia, attended by T. H. Kiilsgaard, J. A. Reinemund, and E. W. Tooker. Reinemund also was a member of the delegation to the U.N. Natural Resources Committee meeting in Tokyo, Japan, and J. E. Case represented the USGS in a workshop sponsored by the Intragovernmental Oceanographic Commission and the NSF, which was held in Honduras in June to plan a program of research for the Caribbean region under the International Decade of Ocean Exploration. D. F. Davidson was the U.S. delegate to the Minerals Advisory Committee of CENTO at the annual meeting held in Teheran, Iran, in December 1974 and to the CCOP meeting in Seoul, Korea, in August. On behalf of UNESCO, R. K. McGuire served as consultant in preparing for a survey of the seismicity of the Andean region (Argentina, Bolivia, Colombia, Chile, Ecuador, Peru, Trinidad, Tobago, and Venezuela). S. T. Algermissen and D. M. Perkins initiated a project for a seismic risk map of southern Europe under an agreement with UNESCO as a part of the UNESCO Balkan Seismologic Project. J. P. Albers, as U.S. delegate, attended the U.N. Law of the Sea Conference, which was held in Caracas, Venezuela, for 10 weeks in June through August 1974; V. E. McKelvey attended the third session of the conference in Geneva, Switzerland, early in 1975.

RESPONSE TO NATURAL DISASTERS

The USGS has been designated by the Department of State as the lead agency in coordinating the U.S. response to natural disasters. As part of this effort, AID provided funds for the USGS to assist in establishing a Nicaraguan Center for Earthquake Hazard Reduction in Managua. The center will study seismicity and geologic hazards and determine basic requirements for regional zoning and construction design. During 1974, USGS personnel on part-time assignments advised on the installation of necessary equipment and trained three Nicaraguans. On behalf of AID, C. J. Robinove completed a study of the potential uses of satellite imagery for warning and assessment of disasters throughout the world. Floods, fire, glacial movement, and drought are the disasters most amenable to satellite sensing. Applications to other disasters such as earthquakes and volcanic eruptions are promising.

MINERALS ATTACHÉ PROGRAM

An expanded minerals attaché and reporting program, proposed jointly by the USGS and the Bureau of Mines, was approved and is being established by the Department of State. Attachés will be stationed

initially in Johannesburg, South Africa; Rio de Janeiro, Brazil; New Delhi, India; Kinshasa, Zaire; La Paz, Peru; and Canberra, Australia. Orientation courses to acquaint these attachés with the operations and information needs of the USGS and the Bureau of Mines have been developed; the first course will be given early in 1976. Minerals attachés will have greater responsibilities than they did in the past, since there is a serious need for accurate information not only on worldwide production of minerals in short supply in the United States but also on the availability of foreign supplies of these minerals for meeting world requirements in the future.

SUMMARY BY COUNTRIES

ARGENTINA

J. M. Botbol and R. W. Bowen completed a 6-week assignment with the United Nations to evaluate the initial design stages of a data bank project. Their study analyzed the mineral-resource data bank, its relation to other projects, its design, and its potential for growth.

BOLIVIA

In a recently completed study of cadmium-rich deposits of the Berenguela district near the common corner of Bolivia, Chile, and Peru, C. M. Tschanz reported that the rare cadmium sulfide, hawleyite, and sphalerite and wurtzite containing as much as 18 percent cadmium were found in concentrically banded schalenblende nodules from lead-zinc-cadmium-copper-silver veins collected by T. H. Kiilsgaard in the early 1960's.

Several systems of cadmium-rich veins and cadmium-bearing thermal spring deposits are within an area of about 50 km^2. The veins average 2 to 6 percent Cd but locally contain as much as 13 to 15 percent. The district is within a north-south belt just east of an active volcanic chain that contains several other widely scattered cadmium-rich base-metal deposits.

The highest cadmium content and the lowest zinc-cadmium ratios (1.1 to 1.5) are in concentrically banded nodules that contain a few thin layers of orange hawleyite and many layers of sphalerite, wurtzite, galena, and other minerals. The hawleyite, earlier identified by M. E. Mrose (written commun., 1969), was the third reported occurrence of this mineral. The extremely high cadmium content of some sphalerite and wurtzite, which was identified from X-ray powder-diffraction films of hand-picked grains by Tschanz, was first suspected by B. F. Leonard because of the expanded cell dimensions and later proved by G. A. Desborough's microprobe analyses.

In one nodule containing hawleyite layers, Desborough found ranges of from 0.14 to 18.0 percent Cd and 56.9 to 65.9 percent Zn in 26 zinc sulfide layers with very low contents of iron and manganese. Ten of these layers contained 11.5 to 18.0 percent Cd, in comparison with a maximum of about 4.7 percent in layers of sphalerite and wurtzite previously reported in the literature. Only six zinc sulfide layers contained less than 1.8 percent Cd. Two or three zinc sulfide layers analyzed in two other nodules had cadmium contents of 0.32 to 2.6 and 4.6 to 9.8 percent. The higher values were in a nodule that did not contain layers of hawleyite. Greenockite, the only cadmium mineral reported in the literature on the district, was not found and probably was reported as the result of erroneous identification of mixtures of hawleyite, wurtzite, and sphalerite.

BRAZIL

The program of technical cooperation with Brazil was focused in 1974 on training participants in the United States, on technical training and consultation by USGS personnel on short assignments in Brazil, and on consultation visits to the United States by senior Brazilian officials.

A total of 37 Brazilian geologists, hydrologists, and technicians received formal training at universities in the United States and in laboratories and field programs of the USGS. Specific advisory assistance and technical training included field and lecture courses in (1) field geology, (2) sedimentary, igneous, and metamorphic petrology, (3) structural geology, (4) weathering processes, (5) field geochemistry, (6) photogeology and remote sensing, and (7) magnetic surveying. A total of 24 USGS specialists on short-term assignments in Brazil provided the training and advisory assistance.

In October 1974, agreement was reached between AID, the USGS, and the Brazilian Ministry of Mines and Energy on an extension, through 1975, of the loan program, which was to have expired in 1974.

Studies of regional aeromagnetic data from Minas Gerais made by W. F. Hanna and A. H. Chidester as part of a training course in Rio de Janeiro indicated that highly distinctive anomalies are associated with various types of igneous rocks having limited ex-

posures. Broad areas of short-wavelength anomalies corresponding to diverse magnetization inclinations correlate with extensive basaltic flows, presumably possessing strong remanent magnetization. Narrow northwest-trending linear anomalies that extend continuously for over 150 km are associated with nearly vertical diabase dikes outlining zones of crustal weakness. Of great economic interest are high-amplitude equidimensional negative anomalies, each flanked by smaller positive anomalies to the north and to the south, which are caused by the induced magnetization of alkalic igneous rock intrusions and their weathering products, rich in Nb, Ta, Sn, Tl, U, and rare-earth elements. The aeromagnetic data provide an almost indispensable tool for regional geologic mapping.

During 1974, six USGS short-term advisors assisted Brazilian agencies with measuring stream discharge by indirect methods, using satellite data for river-basin management, analyzing hydrologic data, collecting and evaluating water-quality data, and applying mathematical modeling to hydrology.

COLOMBIA

The cooperative program between the USGS and its Colombian counterpart, the Instituto Nacional de Investigaciónes Geológica-Mineras (INGEOMINAS), neared completion in 1974. AID agreed to an extension of the loan through 1975, but activity after April 1975 was to be limited to training and consultation by USGS personnel on short-term assignments in Colombia and to academic training of Colombian participants in universities and USGS facilities in the United States.

Under the program in 1974, purchase and installation of equipment in analytical and laboratory facilities brought these facilities to a high level of competence. Academic training in the United States was provided to Colombian participants. On-the-job training and instruction in geologic mapping and mineral-resource evaluation provided valuable experience to a cadre of Colombian geologists in the Popayán district; associated investigations disclosed potential mineral resources. USGS consultants provided technological assistance in the development of identified potential mineral deposits.

Under the direction of D. L. Rossman, 10 Colombian geologists almost completed geologic mapping and geochemical sampling of an area of nearly 15,000 km^2 in the vicinity of Popayán. An ancient gold placer was rediscovered, and several areas of anomalously high Cu, Au, Sb, Zn, and Hg were noted. Several of these areas having potential economic value will be investigated further.

M. R. Brock and J. H. McCarthy, Jr., sampled a bed of limestone adjacent to a lead-silver vein in the Ubalá area. Spectrographic analysis of the samples indicates a content of 2 percent Pb and 93 g Ag per tonne. A program of shallow drilling in this area and prospecting in the vicinity of numerous similar occurrences in the region was planned by INGEOMINAS to evaluate the possible Mississippi Valley-type base-metal deposits.

Geochemical investigations were carried out by J. G. Evans and Colombian counterparts in the Bucaramanga area and by McCarthy in the Gachalá-Ubalá areas. Analytical work on the samples is being done by INGEOMINAS.

J. B. Cathcart reported that geologic investigation and mineral-beneficiation studies of phosphate deposits in Colombia indicate that several deposits can be mined in the near future and that potential phosphate resources in Colombia are large. The TVA has undertaken a program of sampling, physical and chemical testing, and beneficiation at Sardinata, following a plan devised by Cathcart.

COSTA RICA

A. M. Rogers served as an instructor in seismographic data recording and data analysis for the Escuela Centroamerica de Geología at San José, Costa Rica, under the sponsorship of the Organization of American States. He also evaluated the present seismograph stations in Costa Rica.

W. D. Carter advised the AID mission in methods of obtaining data for a cadastral survey of the Rio Chambacú area of north-central Costa Rica.

INDONESIA

USGS assistance project

The AID-sponsored Indonesian project was concluded December 31, 1974, after completing its scheduled 5-yr program. Although its main efforts were devoted to increasing the geologic mapping and map publication activities of the Geological Survey of Indonesia (GSI), support was also provided in geophysics, analytical work, fission-track age dating, and geochemistry.

GSI is publishing geologic quadrangle maps of Java in color at a 1:100,000 scale and off Java at a 1:250,000 scale. In addition, the geology of 16 maps covering all of Indonesia at a 1:1 million scale is being compiled from previous work and current geo-

logic mapping. At the end of 1974, five maps of Java, one of Sumatra, and two of Sulawesi had been published. Color proofs were being reviewed of 3 Java maps, 1 Sumatra map, 1 island of Sumbawa map, and the first of 16 maps at a 1:1 million scale. Cartography or field work were in progress on another 15 maps.

Most of the maps cover areas of economic interest and provide the geologic background for mineral studies. Other maps. such as those of Sulawesi and Timor, cover areas critical to the interpretation of plate tectonics.

A two-man project continued the geological mapping and map publication support into the first 3 mo of 1975.

Topographic mapping

As a result of a request from the Government of Indonesia and AID, the Topographic Division of the USGS agreed to send a mapping specialist to Indonesia to evaluate its mapping capabilities and assist the Government in developing a coordinated national mapping plan. This plan would meet requirements for natural-resource appraisal and development, land-use studies, and identifying priorities with surveying and mapping to meet short- and long-range objectives. The report resulting from this study was completed and transmitted to Indonesia.

Multispectral remote-sensing projects

A multidisciplinary remote-sensing project was initiated in 1973 in Indonesia using the relatively simple multispectral aerial camera as a remote-sensing tool. In January 1974, a team consisting of S. J. Gawarecki, K. H. Szekielda, and R. R. Thaman assisted Indonesian scientists in interpreting multispectral data from an aerial survey of the island of Bali. Eleven Indonesian investigators from agencies involved in agriculture (soils and pest control), fisheries, forestry, geology, land-use studies, and oceanography participated.

Plate tectonics of the Indonesian region

The integration of data from onshore and offshore geologic investigations with marine geophysical and seismological data yielded much insight into plate-tectonic history and processes in W. B. Hamilton's continuing study of Indonesia and a large surrounding region. Throughout Cenozoic time, this region absorbed the complex subduction and strike-slip faulting by which Australia and the Indian Ocean moved northward and the Pacific Ocean moved west-northwestward relative to mainland Asia. As the megaplates move steadily along, small plates break off or form by spreading, deform internally, or fuse to other plates; subducting arcs on the edges of plates collide with other arcs or plates; subduction ceases at one side of an arc and starts at the other. Great wedges of mélange and imbricated sedimentary and crystalline rocks are scraped off against the overriding plates of the subduction zones. Some of the processes under study are also those that cause the formation of deposits of metallic minerals and of some types of oil fields; the developing synthesis has already assisted in focusing the search for metals and fuels in the region.

KENYA

N. E. McClymonds, in cooperation with the Kenyan Ministry of Water Development, made reconnaissance ground-water studies in Northeastern Province. Drilling of test holes and production wells, intended primarily to support Kenya's National Range and Ranch Development Project, began at the end of 1974.

MEXICO

The 5-yr Mexico-U.S. cooperative program of mineral exploration in the Sonoran environment, sponsored by the NSF, emphasizes copper exploration. As a part of this program, M. D. Kleinkopf and counterpart collaborated on establishing the Inter-American Geodetic Survey datum at new gravity bases at Nacozari and other points and made plans for the continuation of the geophysical program.

G. H. Allcott, principal investigator for the program, and his associates completed geochemical sampling in the La Florida-Barrigon district, and a geologic map at a 1:10,000 scale was prepared covering 40 km^2 of the district in the area of the north-trending Sierra Copercuin.

In May 1974, in cooperative investigations with the Consejo de Recursos Naturales No Renovables of Mexico, the USGS discovered a phosphate deposit in the Miocene Monterrey Formation. Fieldwork showed that the deposit has a strike length of 50 km, is at least 100 m wide at the outcrop, and can possibly be mined for at least 200 m under some overburden; the thickness of the bed ranges from about 1 to at least 2.5 m. The P_2O_5 content ranges from 5 to about 20 percent and probably averages about 15 percent. The rock consists of (1) carbonate fluorapatite in rounded pellets and scattered nodules and (2) quartz grains cemented by a mixture of clay (kaolinite), cristobalite, and clinoptilolite. Sparse calcite is pres-

ent in some samples, and some pellets may be phosphatized foraminifers. Since drilling has not yet been done, the extent of the deposit in the subsurface is not known. From the surface data, at least 30 million tonnes of material may be present close enough to the surface to be mined by open-pit methods. The potential for this deposit is very large; similar phosphate is present in the Miocene of southern California. If the phosphate beds are continuous or semicontinuous, the deposit could be very large. Rock minable under present conditions, however, may be limited to the moderate tonnage that can be mined by open-pit methods.

NEPAL

G. C. Tibbitts, Jr., and William Ogilbee, in cooperation with the Nepalese Department of Irrigation and Hydrology, completed two ground-water exploration projects in the western Terai of Nepal.

In the 1,800-km^2 Bheri Zone, 45 test holes (a total of 8,077 m drilled) showed that large-yield wells are not uniformly distributed. In the northeastern part of the zone, adjacent to the Siwalik Range, naturally flowing wells occur. Analyses of water from wells in the area showed a low to very low sodium content and medium to high salinity.

In the Seti and Mahakali zones, an area of 3,720 km^2 west of the Bheri Zone, 45 test holes (a total of 5,882 m drilled) showed that well yields vary, but the potential for irrigation water from wells is good. In much of the area, artesian pressure is high, and precautions must be taken in constructing wells. Analyses of water from wells indicated that sodium content is low to very low and salinity is average.

OMAN

The mineral resources of northern Oman were investigated by R. G. Coleman and E. H. Bailey under an agreement between the USGS and the Ministry of Development of the Sultanate of Oman during late 1973 and early 1974. The purpose of the investigation was to evaluate the mineral potential of northern Oman and to recommend ways to utilize any viable mineral deposits that were found. Economically, the most important rock unit in the Al Hajar (Oman Mountains) is the Semail ophiolite because nearly all the ore deposits are associated within it. The Semail ophiolite is considered to be a slab of ancient oceanic crust thrust onto the edge of the Arabian plate during Late Cretaceous time. The oceanic crust apparently formed at a spreading center within the Tethyan Sea some time during the Mesozoic. The most significant ore deposits are copper-bearing massive sulfides situated near the top of the Semail pillow lavas; commonly associated with these sulfide bodies are iron-rich sediments (umbers). The surface expression of these massive sulfides is characterized by brightly colored gossans, and ancient slag piles are situated near many of them. Archeological evidence suggests that the Oman copper deposits may have been worked as early as 2500 B.C. and could have been the source of copper used in the ancient city of Dilmun, on the island of Bahrain. The geologic similarity between the copper-bearing massive sulfide deposits of Cyprus and Oman is striking. From this analogy and the most recent research on the origin of the Cyprus deposits, it seems that the Oman deposits are produced by sea-floor-spreading processes rather than from a postemplacement hydrothermal source. Drilling of the gossans by a Canadian exploration firm (Prospection Ltd.) revealed considerable tonnage of ore-grade copper. The USGS investigation revealed also the presence of chromite in the ultramafic parts of the Semail ophiolite, along with extensive Maestrichtian iron laterite developed on the tops of the exposed ophiolite.

PAKISTAN

Maps prepared by digital computer classification of LANDSAT–1 MSS data were used by R. G. Schmidt to select 30 prospecting targets in the Chagai District of Pakistan; 5 of these proved to be areas of hydrothermally altered porphyry containing abundant pyrite. At least part of the mineralized porphyry is copper bearing.

The known porphyry copper deposit at Saindak was used as a control or training area from which empirical maximum and minimum apparent reflectance limits were selected for each of four MSS bands in each rock type classified, and a relatively unrefined classification table was prepared. Where the values for all four bands fitted within the limits designated for a particular class, a symbol for the presumed rock type was printed by the computer at the appropriate location, and a classification map was formed. Drainage channels, areas of mineralized quartz diorite, areas of pyrite-rich rock, and the approximate limit of propylitic alteration were very well delineated on the computer-generated map of the control area.

The classification method was then applied to the evaluation of 2,100 km^2 in the western Chagai Hills east of the control area. During October 1974, a par-

tial check of the results was made in the field in cooperation with the Government of Pakistan's Resource Development Corporation. Thirty prospecting targets were selected by evaluating the digital classification map, and 19 were visited. Of these, 5 localities comprising a total outcrop area of 4.7 km^2 are hydrothermally altered rock, mostly silicified and containing sericite and clay minerals and 5 to 10 percent pyrite. The pyritic rock is believed to be the pyrite zones of porphyry copper-type deposits. One sample of unleached rock contained 0.3 percent Cu, but the presence of copper or other valuable metals beyond trace amounts has not been established for most of the altered area. Three of the five sites may be parts of the same partly hidden mineralized area.

Surficial rock in the altered areas is intensely leached; the former presence of sulfides is indicated by voids, ochers, and iron-oxide stains. Residual blocks still containing fresh sulfide are relatively rare. Secondary copper minerals are present at a few places but are very sparse in most of the leached rock. Schmidt was not able to judge how much copper was present before leaching, but, if even a minor amount was there, the possibility of a secondary enriched zone at depth seems very good.

The results of the experiment show that outcrops of hydrothermally altered and mineralized rock can be identified from LANDSAT–1 data under favorable conditions. The empirical method of digital computer classification of the MSS data is relatively unrefined and rapid. The five mineralized prospecting sites identified are in a generally favorable region, but no sulfide mineralization was known near these places when the investigation began.

PERU

Excellent short- and long-period seismograms registered a large landslide in the Peruvian Andes. The approximate location was 185 km southeast of Huancayo. The landslide, which took place April 25, 1974, created a very large natural dam on the Mantaro River. A microearthquake field unit was deployed by the Instituto Geofisico del Peru in order to monitor the postlandslide activity. Some of the results of this study are: (1) The seismic recordings showed a multiple landslide mechanism (the largest landslide had a magnitude of 4.7) and a total seismic release energy of 6×10^{19} ergs; (2) the time delay between landslides is between 40 and 50 s; and (3) the total time duration was 4 min. This landslide was the first of this order of magnitude to be recorded so clearly to distances of 580 km on long- and short-period seismograph systems. This work was a joint effort by members of the Instituto Geofisico del Peru and a member of the Geological Survey of Peru, with USGS participation.

POLAND

The USGS, under a Department of Interior agreement with the Government of Poland under the Special Currency Program (Public Law 480), is responsible for monitoring Poland's Earth-science research projects. One project involves the influence of mining on the water economy in an area near Katowice in the Upper Silesian lead-zinc and coal basin. G. C. Taylor, Jr., and A. V. Heyl reported that 10 to 12 t of water must be pumped for each tonne of ore taken from mines in karstic dolomites and limestones in a 4,500-km^2 area. About 500 m^3/min of water of acceptable chemical quality is pumped from lead-zinc mines in Triassic carbonate rocks, and about 180 m^3/min is pumped from coal mines in carboniferous clastic rocks. An additional 420 m^3/min of water from coal mines is saline and cannot be used; carbon-14 analyses of the coal mine saline water showed that it is more than 40,000 yr old.

SAUDI ARABIA

A work agreement for investigations in Saudi Arabia was signed by the USGS and the Saudi Arabian Ministry of Petroleum and Mineral Resources in 1963, and work begun then has been extended four times, each extension for a 3-yr period. The third extension of the work agreement became effective December 1, 1972, and ran until September 12, 1975. However, the USGS negotiated a fourth extension of the work agreement to begin in July 1975 and continue for 3 yr in accordance with the Hegira calendar. Emphasis in the third program was on detailed geologic mapping as an aid to mineral exploration and on the improvement of the Ministry's technical capability.

Mahd adh Dhahab

R. G. Worl and R. J. Roberts (USGS) and Abdulaziz Bagdady (Saudi Arabian Ministry of Petroleum and Mineral Resources) reported that the geologic perspective of the Mahd adh Dhahab gold-silver district in the central part of the Arabian Shield suggests a significant resource that may be minable in the near future. This evaluation is based upon detailed mapping, surface geochemical surveys, detailed study and analysis of core samples from eight diamond-drill holes, examination and synthesis of

all older geologic and economic data, a detailed report prepared by an outside consultant, and the examination and evaluation of the district by several mining and exploration firms.

Two types of deposits are being evaluated: relatively high grade but erratically distributed vein deposits and large-tonnage low-grade deposits. Both types are situated in a north-trending zone of veining, shearing, alteration, and metallization 1,000 m in length and at least 200 m in width. Limited diamond drilling in the southern and central parts of the zone has penetrated several metal-bearing veins. The largest metallized intercept is 24 m of core length (19.2 m true width) that averages 11 ppm (g/t) Au, 60 ppm (g/t) Ag, 0.5 percent Cu, and 1.2 percent Zn. A higher grade zone within this 24 m is a 6-m core length (4.8 m true width) that averages 42 ppm (g/t) Au and 207 ppm (g/t) Ag. Further exploration is planned in this zone. The area of the low-grade deposit, in the northern end of the zone, was intensively mined during ancient times (1000 B.C. and 750–1258 A.D.) and by the Saudi Arabian Mining Syndicate in 1930–54. Early production is not known but may have exceeded 31,103 kg gold-silver bullion; production in 1939–54 totaled 23,818 kg fine gold and 31,166 kg silver. Most of the high-grade veins have been mined from this deposit, but significant gold-silver values remain in intervein areas and in veins too narrow to be stoped. The deposit is exposed over an area of about 100,000 m^2; further studies to evaluate the grade of material in this block are planned.

Kutam

Regional and detailed mapping by R. E. Anderson in the Kutam area clarified events bearing on the genesis of mineralization. The sequence of events follows:

1. Ancient layered sedimentary and volcanic rocks were tilted and invaded by quartz porphyry sills. Subsequently, all rocks were metamorphosed to the amphibolite facies and were locally silicified.
2. Subsequently, during retrograde metamorphism, biotite, muscovite, and garnet were replaced by chlorite. Plagioclase was replaced by epidote, zoisite, and calcite.
3. Later, temperature was reelevated; during emplacement of large granodioritic to quartz monzonitic plutons, the rocks were recrystallized, and hornblende, plagioclase, and biotite were formed.
4. Subsequent copper and zinc mineralization evidently followed the recrystallization period. Gahnite in association with quartz indicates anomalous concentrations of zinc in a contact metasomatic environment. Examination under the microscope indicates that the gahnite was partially altered to mica and sphalerite during the simultaneous deposition of zinc and copper sulfides, the suggestion being that the environment degraded from a high-temperature metasomatic to a lower temperature hydrothermal. Possibly the anomalous mass of highly foliated rock at the Kutam prospect served as a permeable channelway for the passage of metal-bearing solutions during the final phases of the contact metasomatic recrystallization event and a subsequent lower temperature hydrothermal event. Accordingly, the sulfide mineralization and associated silicification are interpreted as being the final events in a long and complex metamorphic history.

Genesis of massive sulfide and disseminated deposits

Massive and disseminated iron, nickel-iron, and copper-zinc sulfide deposits in Saudi Arabia are being studied in the field and laboratory. Field studies by R. J. Roberts, R. G. Worl, F. C. W. Dodge, W. R. Greenwood, R. E. Anderson, and T. H. Kiilsgaard showed that the deposits formed in both volcanic and plutonic rocks. Some deposits in volcanic rocks show finely laminated pyrite (Wadi Wasat, iron; Wadi Qatan, iron and nickel). Initially, these deposits may have accumulated syngenetically, but they have been metamorphosed and complexly deformed. The source of nickel in the Wadi Qatan deposit is considered by Dodge to be late-stage hydrothermal. Assays of samples from the Wadi Wasat deposit indicate a low nickel content; apparently, late-stage hydrothermal processes were weak or absent here.

Copper-zinc massive sulfide deposits at Wadi Bidah are partly in calcareous tuff and partly in intrusive quartz porphyry. R. L. Earhart in earlier work considered these deposits to be volcanogenic, but Roberts and Worl consider them to be epigenetic. Disseminated copper-zinc deposits at Kutam are in a sericite and chlorite schist and in a quartz porphyry intrusive body. According to R. E. Anderson, the sulfide minerals occur mainly at the intersections of two cleavages and are epigenetic. Studies on lead isotopes are being carried on by B. R. Doe and M. H. Delevaux; these studies should further clarify the geologic history of the ore deposits.

Cratonization in the Arabian Shield

The Arabian Shield in southwestern Saudi Arabia was cratonized during the late Proterozoic, according to W. R. Greenwood, D. G. Hadley, R. E. Anderson, R. J. Fleck, and D. L. Schmidt. Early cratonal development began with the deposition of calcic to calc-alkalic and basaltic to dacitic volcanic rocks and immature sedimentary rocks that subsequently were moderately deformed, metamorphosed, and intruded about 960 m.y. ago by dioritic batholiths of mantle derivation ($^{87}Sr/^{86}Sr=0.7028$).

A thick sequence of calc-alkalic andesitic to rhyodacitic volcanic rocks and volcanoclastic wackes was deposited unconformably on this neocraton. Regional greenschist-facies metamorphism, intensive deformation along north-trending structures, and intrusion of mantle-derived ($^{87}Sr/^{86}Sr=0.7028$) dioritic to granodioritic batholiths occurred at about 800 m.y. At about 785 m.y., granodioritic to quartz monzonitic gneisses ($^{87}Sr/^{86}Sr=0.7028$ and 0.7035) were emplaced in part as gneiss domes surrounded by amphibolite- to granulite-facies metamorphic rocks. Extensive deposition of similar volcanic and clastic rocks elsewhere in the region seems to have been in part synchronous with orogeny at 785 m.y. and to have followed it. These deposits and the older rocks were deformed along north-trending structures, metamorphosed to greenschist facies, and intruded by calc-alkalic plutons ($^{87}Sr/^{86}Sr=0.7035$) between 600 and 650 m.y. B.P.

Late cratonal development involved extensive graywacke sedimentation associated with small amounts of andesitic and rhyolitic volcanism, structural deformation, metamorphism to greenschist facies, and intrusion of quartz monzonite and granite between 570 and 550 m.y. Cratonization appears to have evolved in an intraoceanic island-arc environment of comagmatic volcanism and intrusion.

New gravity data in southern Red Sea

A complete Bouguer gravity anomaly map of the Farasan Islands and the adjacent coastal plain was compiled on the basis of 145 observations. The principal features of the map are a troughlike gravity minimum over the Farasans, a row of gravity highs along the eastern part of the coastal plain, and an extremely steep gravity gradient (4 to 5 mGal/km) in the eastern part of the mapped area. The troughlike gravity low over the shelf is interpreted to be caused by anomalous thicknesses of evaporites, and the gravity highs are believed to be associated with observed high-amplitude magnetic anomalies and, in some cases, with exposures of mafic igneous intrusive rocks. Two classes of models were devised, one assuming a downfaulted continental crust beneath the coastal plain and shelf sediments and the other an oceanic crust under the coastal plain and shelf. Computed gravity profiles for the two models show that only the oceanic crust model, which has sediments thinning toward the Arabian Shield, produces a profile that fits both the shape and the magnitude of the observed gravity gradient. This suggests that the gradient, located along the eastern edge of the coastal plain, demarcates the boundary of the continental margin.

THAILAND

D. R. Shawe and R. J. Hite, working in cooperation with counterparts in the Royal Thai Department of Mineral Resources, completed a field appraisal of the geology of parts of Thailand and a study of the relation of known mineral deposits to the geology. It is anticipated that the work will result in a better estimate of the mineral-resource potential than now exists.

Hite continued to cooperate with the Department of Mineral Resources and with scientists of the Government of Laos in evaluating the potential for potash deposits in rocks of the Khorat Plateau.

LANDSAT program

The building of a viable Thai LANDSAT program continued under the leadership of J. O. Morgan, USGS project coordinator, and the sponsorship of the United States Operations Mission in Bangkok. All major Thai agencies involved with agriculture, forestry, geology, and land use are now using LANDSAT data for mapping purposes. A photographic laboratory to print and process LANDSAT images for distribution within Thailand is being furnished and is in operation.

YEMEN ARAB REPUBLIC

Topographic mapping

Eleven 1:20,000-scale metric contour orthophotobase maps of Wadi Mawr were delivered in November 1974 to the Director General of the Tihama Development Authority. Additional work is needed to make the geographic names conform to the transliteration system developed for Arabic by the U.S. Board on Geographic Names. The maps are being used for preliminary planning by irrigation engineers and other specialists making agricultural, population, social, and environmental studies in the area.

Ground-water studies

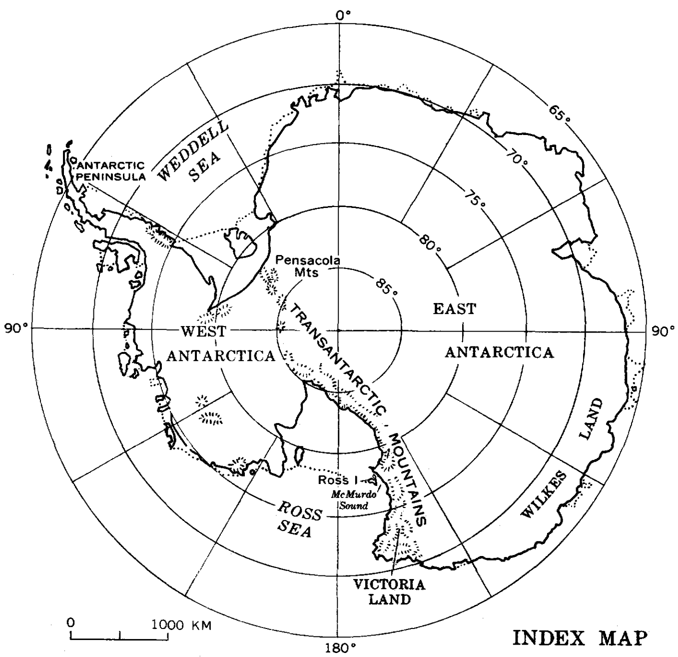
J. J. Jones reported that a 3-yr project begun in cooperation with the Ministry of Agriculture and the Minerals and Petroleum Authority of the Yemen Arab Republic has three segments: (1) A ground-water survey north of lat 15° N., (2) compilation and interpretation of LANDSAT images of the entire country, and (3) a minerals survey north of lat 15° N. The first two activities have begun.

Reconnaissance of water resources was made in selected areas, and five test holes totaling 512 m were drilled. Water levels in the Ṣan'a' basin declined about 2 m during the year, and those in the 'Amran valley declined at varying but lesser rates.

LANDSAT images were compiled for part of the country, and field checking of ground truth was underway at the year's end.

ANTARCTICA

Geologic field studies were not undertaken by USGS personnel during the 1974–75 austral summer in Antarctica. However, work continued on map compilation and on laboratory studies of the petrology, geochemistry, geochronology, and paleontology of samples collected during previous expeditions to the southern part of the Antarctic Peninsula, the Pensacola Mountains, and the central part of the Transantarctic Mountains. (See index map.) These continuing studies, which are part of USARP, are in cooperation with the Office of Polar Programs of the NSF. Progress in Antarctic aerial photography and topographic mapping, which are functions of the USGS, is reported in the next chapter.



INDEX MAP

Chloritic replacement of anthracite plant remains

Woody plant fragments from the southern part of the Antarctic Peninsula are strongly metamorphosed and usually composed of coal similar to that in associated thin beds of anthracitic coal. Plant pieces generally are strongly cleated, having joints characteristically resembling a dense boxwork and containing angular pieces of coal in interstitial spaces. In some examples, however, interstitial material is not coal but consists of a nonswelling chloritic mineral, probably of metamorphic origin, that so closely duplicates the coaly joint pattern that physical replacement is indicated. Even at elevated temperatures in a coke oven, anthracite remains insoluble and inert. However, the Antarctic occurrences suggested to J. M. Schopf that, under high confining pressures in a natural environment, anthracite may dissolve so that bulk interchange with chloritic constituents can take place.

Environmental studies in the Pensacola Mountains

The Pensacola Mountains lie in a remote and seldom-visited part of Antarctica. The area is relatively uncontaminated by the effects of human activity or animal visitations in comparison with areas near Antarctic stations or other more traveled regions. Prior to 1974, except for a brief visit by a 1957 IGY party, the Pensacola Mountains had been visited only by reconnaissance geologic, geophysical, and geodetic survey parties of the USGS. In the expectation that activity in this area will increase in future years, A. B. Ford (USGS), during a brief visit to the northern Pensacola Mountains in January 1974, collected aseptic samples of soils for baseline studies by which to monitor possible effects of future contamination. Three sampled sites are on Rosser Ridge in the Cordiner Peaks, and three are on Mount Lechner in the Forrestal Range. The soils were analyzed for abiotic properties and microorganism contents by R. E. Cameron (Darwin Research Institute). The Rosser Ridge soils are comparatively more weathered than the Mount Lechner soils and have moisture and mineral contents more favorable for microorganism activity. Coliforms and fungi are absent in the soils from both areas, and bacterial

contents are generally low in comparison with those from other Antarctic areas (Cameron and Ford, 1974).

Age and distribution of radiogenic argon in Antarctic basalt flows and dolerite sills

Jurassic basalt flows and dolerite sills of the Ferrar Dolerite in the central Transantarctic Mountains yield ages ranging from 110 to 180 m.y. by conventional K-Ar analysis. Because these rocks are virtually undeformed and, being the youngest stratigraphic units in the region, were never deeply buried, postcooling thermal disturbance of the ages cannot be invoked as a cause for young ages. Both a reliable time of extrusion of the basalts and a confirmation of an argon-loss interpretation are provided by $^{40}Ar/^{39}Ar$ incremental heating experiments. Flows with the oldest conventional K-Ar ages yield $^{40}Ar/^{39}Ar$ age spectra with plateaus typical of undisturbed samples. These ages group closely between 170 and 175 m.y. The fact that conventional ages less than 170 m.y. are also poorly reproducible suggests inhomogeneous distribution of radiogenic argon. The $^{40}Ar/^{39}Ar$ age spectra from these samples are similarly variable but clearly indicative of argon loss, since ages of gas fractions vary from 180 to 120 m.y. Because age disturbance is greatest in samples with considerable amounts of devitrified glass and is not observed in the few originally holocrystalline rocks, R. J. Fleck (USGS) and J. F. Sutter and D. H. Elliot (Ohio State Univ.) concluded that progressive devitrification of the basalts is responsible for the inhomogeneous distribution of argon, some of which was lost from the rock systems.

TOPOGRAPHIC SURVEYS AND MAPPING

NATIONAL MAPPING PROGRAM

New requirements for basic data to inventory, develop, and manage the country's natural resources are reshaping the national mapping program. A major function of the USGS has been to prepare and maintain maps in the national topographic series, which covers the United States and its outlying areas. This role is now expanding to include basic map data as well as a family of general-purpose maps.

The national mapping program is initially focusing on 11 categories of base-map data: reference systems, hypsography, hydrography, vegetative cover, nonvegetative features, boundaries, transportation systems, other manmade features, geodetic control and survey monumentation, geographic names, and orthophotographic imagery. Other map data of public value may also be incorporated into the program; under a cooperative agreement, the agency responsible for the data can arrange for the preparation of maps or other forms suited to its needs.

The major products of the program are:

1. Digital data. The program's goal is to supply the base-map data in digital form for reasonable areas of the country within 30 d of a request.
2. Orthophotos. Once a byproduct of the mapping process, the orthophoto has become an important product in its own right. Orthophotos are produced quickly and inexpensively and provide a wealth of information not available on line maps.
3. Cartographic data. The availability of base data in graphic form is being expanded. Reproducibles that are feature separated as well as color separated facilitate the preparation of special-purpose maps.
4. Line maps. The traditional multipurpose line map is still an important tool and will continue to be produced. In addition to the standard series now available, new series at scales of 1:50,000 and 1:100,000 are being produced.

Procedures for obtaining map products are given in the section "How to Obtain Publications" in the chapter on "U.S. Geological Survey Publications."

MAPPING COORDINATION AND REQUIREMENTS

The USGS has the authority to coordinate federally funded domestic mapping activities. For an effective and economical response to national mapping needs, the USGS coordinates departmentwide geodetic and mapping control surveys; identifies and evaluates national mapping requirements; fosters cooperative mapping, charting, and geodesy research and development; and operates the National Cartographic Information Center for ready exchange of cartographic data gathered by government agencies and some private organizations. During the past year, this coordination included several noteworthy projects:

1. Consulting with the Bureau of Land Management to determine requirements and refine specifications for intermediate-scale maps to support area studies and planning for programs of national concern.
2. Assisting the Bureau of the Census with its specific cartographic requirements, such as the full-line UTM grid and single-line road symbols, to minimize the task of converting USGS quadrangles into computer-compatible base maps of road networks.
3. Confirming Soil Conservation Service (SCS) requirements for an intermediate-scale base map. According to a cost-sharing agreement, the USGS will prepare planimetric bases for farm-soil inventories for selected counties in each State, and the SCS will add soil data and handle publication.
4. Preparing 1:24,000-scale orthophotoquads for SCS use as bases for soil-survey publications. This cost-sharing program comprises 52 projects, or 1,700 orthophotoquads; an additional 1,600 orthophotoquads will be authorized shortly.

5. Producing a handbook on coastal zone mapping to help States comply with the Coastal Zone Management Act of 1972. The handbook is a joint effort of the USGS and NOAA and will be completed by December 1975.
6. Experimenting in combining National Ocean Survey bathymetric contour data with topographic maps to produce a topographic-bathymetric map series for coastal zones.
7. Cooperating with the U.S. Fish and Wildlife Service on the preparation of aerial photograph indexes needed for wetland inventories.
8. Documenting the need for a large-scale urban map series. Private mapping firms prepared, to USGS specifications, large-scale orthophotographic maps for Fort Wayne, Ind.; Charleston, S.C.; Frederick, Md.; and San Francisco, Calif.; the maps are now in the hands of users who will provide feedback on applications. As the various functions of city and county governmental agencies become clearer, the USGS will learn how they can be better served by maps or related cartographic data.
9. Surveying the requirements of selected Federal and State agencies, regional planning commissions, universities, and county surveyors. Most favor the full UTM grid on 7½-min quadrangles, particularly where digitization of map data is planned. Slope maps appear desirable for areas prone to flooding, faults, and landslides. State highway departments generally view a county map series as useful in their work, provided that the information can be easily updated.

NATIONAL CARTOGRAPHIC INFORMATION CENTER

The National Cartographic Information Center (NCIC) was established in 1974 to provide a central repository for information on all U.S. cartographic data—maps, charts, aerial photographs and space images, geodetic control, and spatial data in digital form. Cartographic data are acquired and held by over 30 Federal agencies, all States, and innumerable private organizations, but the data have not all been easily accessible, and some duplication of effort has resulted.

The NCIC plans to meet the increasing need for cartographic data for resource exploration and development, land and water-resource management, land-use planning, and environmental protection. In order to become a single service center for all cartographic materials, the NCIC is inventorying the holdings of various agencies and developing information systems to make these data readily available, initially through referral and ultimately through direct handling of orders.

In August 1974, over 30 Federal agencies conferred with the USGS on the objectives of the NCIC. During March and June 1975, the NCIC met with agencies that have major holdings of aerial images to discuss automated indexing systems and arrange for input. Data management agreements are being pursued; some are already in effect, such as those with the National Ocean Survey for consolidating geodetic control information and with the EROS Data Center on aerial imagery programs.

The NCIC has formed a high-altitude photography summary record system (HAP) that will rapidly provide participating agencies with information on existing and planned high-altitude photography. Summary records describe the geographic extent and general characteristics of aerial photographs that are acquired, in progess, or planned by an agency. The system output is computer-generated listings and graphics showing the available coverage meeting specified criteria. A standard set of graphics will be published and distributed regularly by the NCIC; users will also be able to request special searches. Negotiations are underway with Federal agencies for direct input to HAP. In fiscal year 1976, HAP will be expanded to include aerial imagery holdings and plans of State and local agencies and private organizations.

System design is also well underway on the map and chart information system. The data bank already includes a complete listing of all USGS topographic maps, both current and historic. These maps are also being microfilmed on 35-mm black-and-white film. The computerized quadrangle map file will be expanded to include maps and charts of various sources and kinds covering any area of the United States. The system is scheduled to be in operation by July 1976, when it will be possible to query the file from remote terminals at several locations across the country.

The Defense Mapping Agency digital terrain tapes are now available from the NCIC. These tapes contain data digitized from the 1:250,000-scale topographic map contours for the 48 conterminous States. The NCIC also offers status and ordering information for digital data on land use, census tracts, political boundaries, hydrologic basis boundaries, and Federal land ownership, which are being collected for the USGS Land-Use Data and Analysis program.

The success of the NCIC depends largely on the cooperative efforts of the organizations that collect, produce, and distribute cartographic data. First reactions from 20 Federal agencies have been highly favorable. The NCIC publishes a quarterly newsletter, and a "User Guide" to NCIC services will be available soon.

MAPPING ACCOMPLISHMENTS

Quadrangle map coverage of the Nation

General-purpose topographic quadrangle map coverage at scales of 1:24,000, 1:62,500, 1:63,360 (Alaska), and 1:20,000 (Puerto Rico) is now available for about 92.6 percent of the total area of the 50 States, Puerto Rico, the U.S. Virgin Islands, Guam, and American Samoa. Included in this coverage is about 3.8 percent of the total area, not yet published but available as advance manuscript prints.

During fiscal year 1975, 1,468 maps were published covering previously unmapped areas, equivalent to about 2.3 percent of the area of the 50 States and territories referred to above. In addition, 484 new maps at a scale of 1:24,000, equivalent to about 0.8 percent of the total area, were published to replace 15-min quadrangle maps (1:62,500 scale) that did not meet present needs. Figure 6 shows the extent and location of the current topographic map coverage.

Map revision and maintenance

As maps become out of date, revision is necessary to show changes in the terrain and changes and additions to manmade features, such as roads, buildings, and reservoirs. During fiscal year 1975, 907 general-purpose quadrangle maps of the 7½-min series (1:24,000 scale) were revised. Most of these revised maps are in large metropolitan areas and their expanding suburbs and in States that are completely mapped in the 7½-min series that have cooperative programs for a regular updating. About 57 percent of the 1,746 maps currently in the revision program (fig. 7) are being updated by photorevision—a low-cost rapid production method that relies primarily on photointerpretation. Recent aerial photographs of the areas to be revised are inspected, and changes in cultural and other planimetric features are mapped and printed in purple on the revised map.

An inspection program, started in fiscal year 1972, has contributed substantially to reducing the revision backlog. During fiscal year 1975, 1,569 7½-min quadrangles were inspected, and 1,044 were found to need revision. Those not needing revision are noted on the sales indexes, and the inspection date appears on the reprinted maps.

The maps in the revision program that are not photorevised will receive a more complete overhaul, which will include a field check and revision of some or all of the color-separation drawings.

In fiscal year 1975, approximately 1,280 general-purpose quadrangle maps were reprinted to replenish stock.

1:250,000-scale map series

The 48 conterminous States and Hawaii are completely covered by 473 topographic maps at 1:250,000 scale. Originally prepared as military editions by the Defense Mapping Agency (formerly the U.S. Army Map Service), the series is now maintained by the USGS. Maps are revised in an average 8-yr cycle, and standard metropolitan statistical areas are revised every 5 yr, provided that adequate source materials are available. Figure 8 shows revisions in progress on 1:250,000-scale maps.

Of the 153-sheet Alaska reconnaissance series, all but a dozen have been replaced with standard maps based on larger scale source materials and on new photogrammetric compilations; these maps are part of the U.S. 1:250,000 series. An active revision program has been established to maintain the currency of the Alaska series.

In cooperation with NOAA, a program to produce topographic-bathymetric editions of 1:250,000-scale maps of the coastal zones of the United States was started in fiscal year 1974. The Beaufort, N.C., experimental quadrangle is the first joint edition; elevations are shown in feet, and water depths are shown in metres. Five additional maps in the series are in progress: Appalachicola, Providence, Gainesville, Tampa, and Plant City, Fla. Topographic-bathymetric editions will be prepared as bathymetric data become available.

Maps in the 1:250,000-scale series are used by the USGS as base copy for the preparation of the State base-map series, the International Map of the World series, and special small-scale maps such as the land-use–land-cover series now in production. The 1:250,000-scale series has also been designated by the Board on Geographic Names as a basic reference for geographic nomenclature in Government publications.

State base-map series

State base maps are published at scales of 1:500,000 and 1:1,000,000 for all States except Alas-

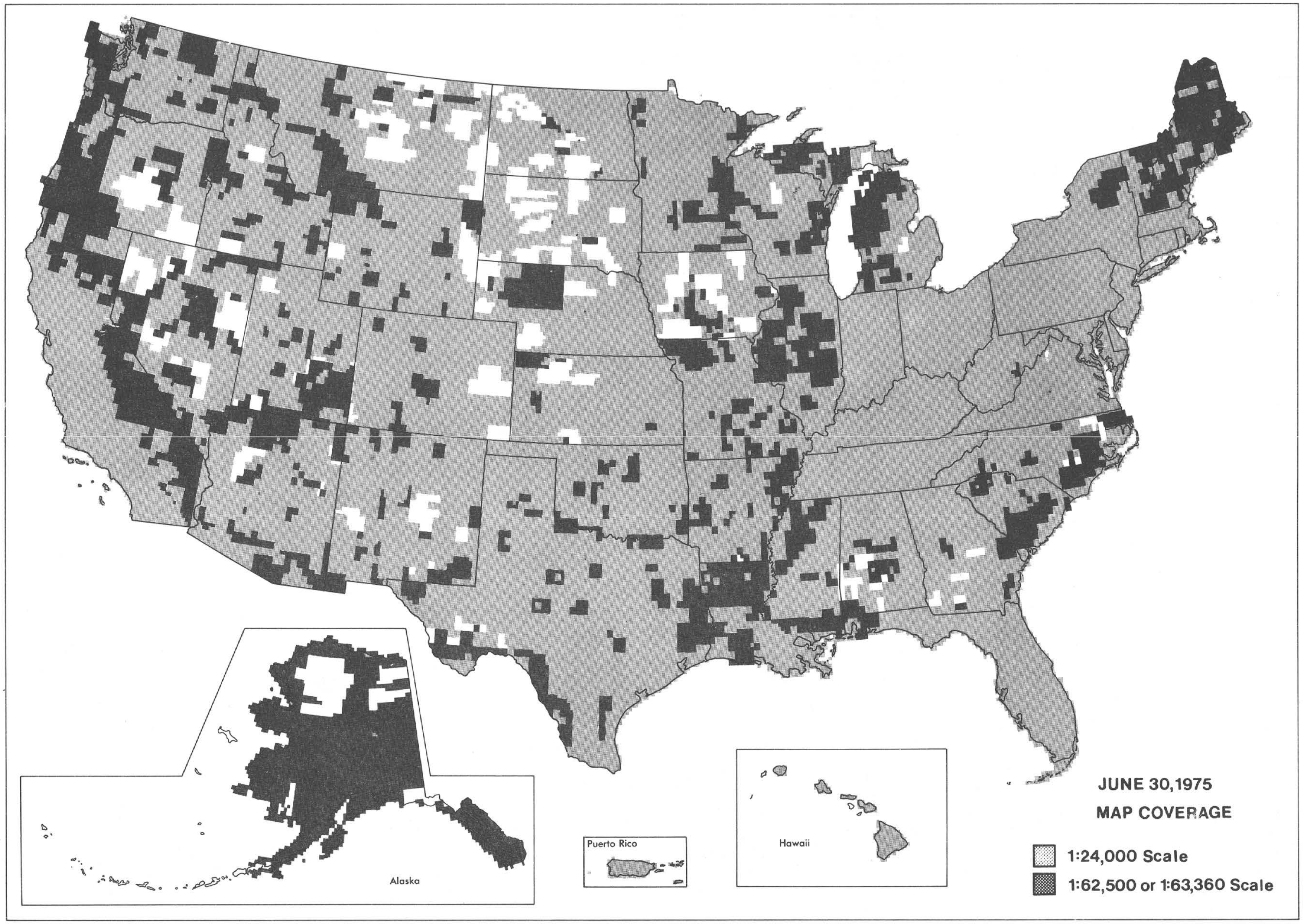


Figure 6.—Status of 1:24,000- and 1:62,500-scale mapping.

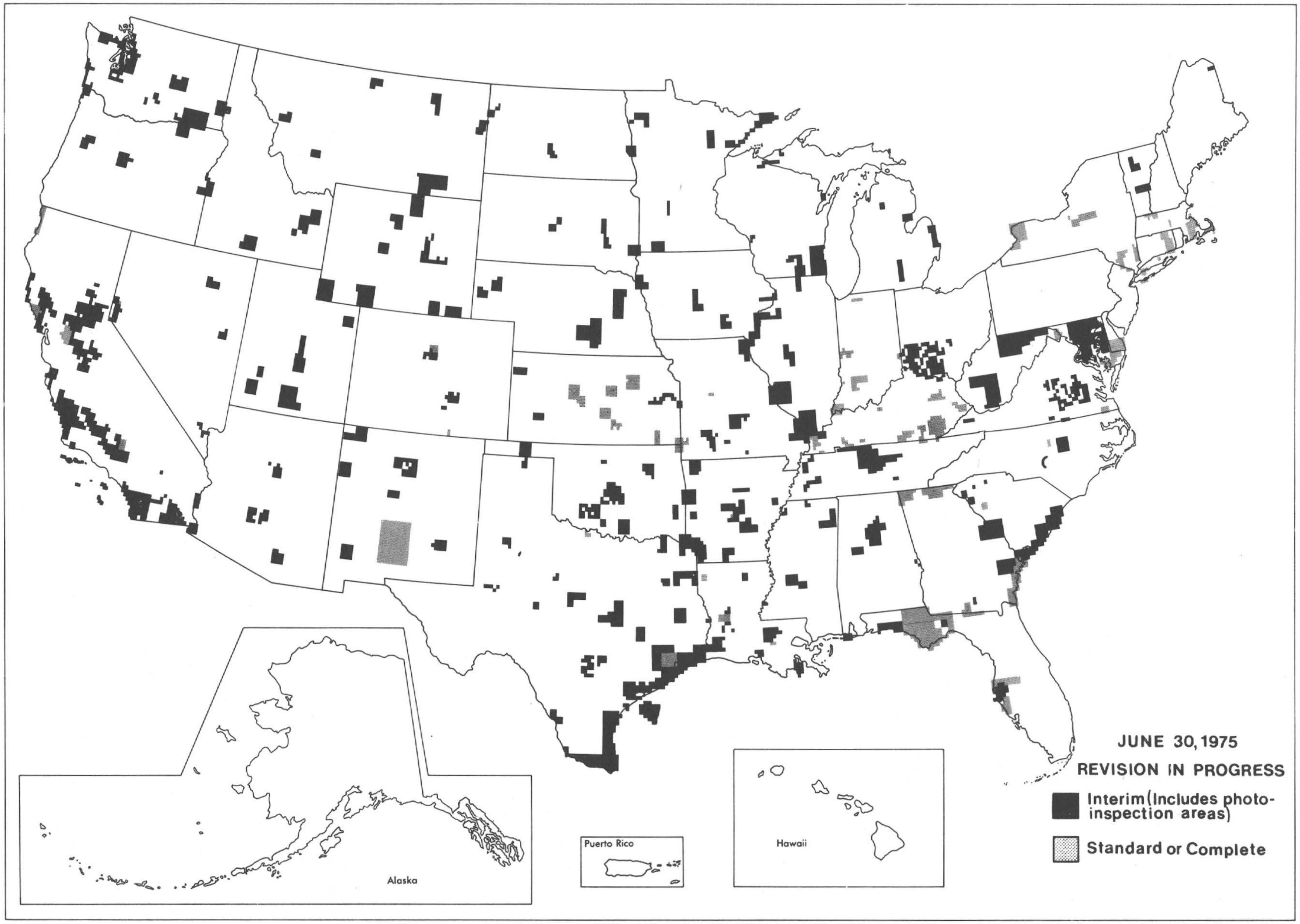


FIGURE 7.—Revision in progress, 1:24,000-scale topographic maps.

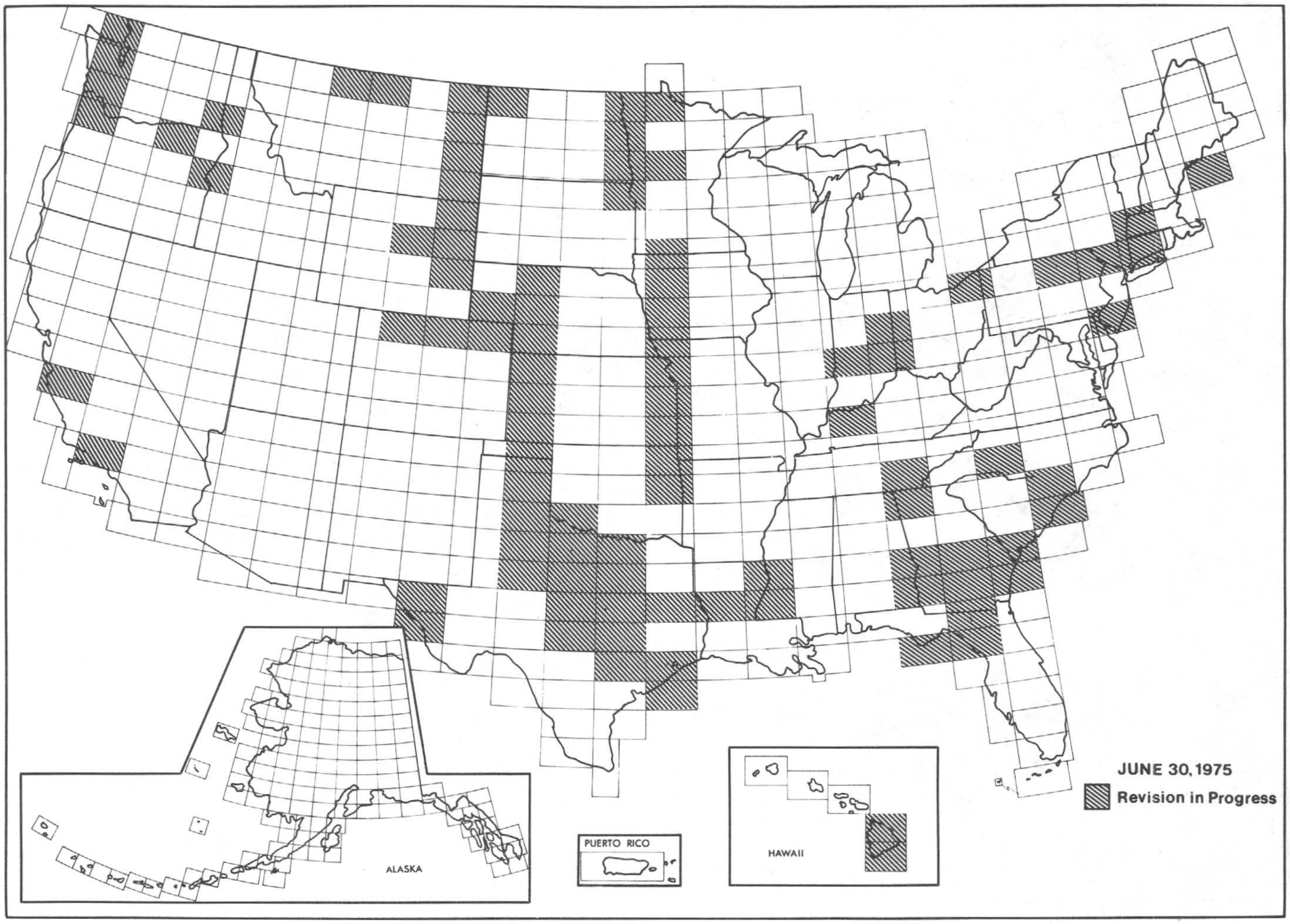


FIGURE 8.—Revision of 1:250,000-scale topographic maps.

ka. State base 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 base map of Connecticut is also available at a scale of 1:125,000. The maps are generally prepared in three editions—base, topographic, and shaded relief—and show urban areas, major communications routes, major hydrographic features, and county boundaries. The series consists of 46 maps covering the 50 States and the District of Columbia; 17 maps are in progress. Figure 9 shows revision progress on the State base-map series.

National park map series

Special topographic maps have been prepared for 50 of the national parks, monuments, historic sites, and other areas administered by the National Park Service that are large enough to require separate editions. They are usually made by combining the existing quadrangle maps of the area into one map sheet, but, occasionally, surveys are made covering only the park area. Many of the maps are also available in a shaded-relief edition. Other parks, monuments, and historic sites are shown on maps in the general-purpose quadrangle series. New or revised maps in preparation include:

Arches National Monument, Utah
Big Bend National Park, Tex.
Great Smoky Mountains National Park, N.C.-Tenn.
Mount Rainier National Park, Wash.
North Cascades National Park, Wash.
Point Reyes National Seashore, Calif.

New or revised maps published in fiscal year 1975 include:

Canyonlands National Park, Utah
Death Valley National Monument, Calif.-Nev.
Glacier National Park, Mont.
Mesa Verde National Park, Colo.
Mammoth Cave National Park, Ky.
Mount McKinley National Park, Alaska
Theodore Roosevelt National Park, N. Dak.

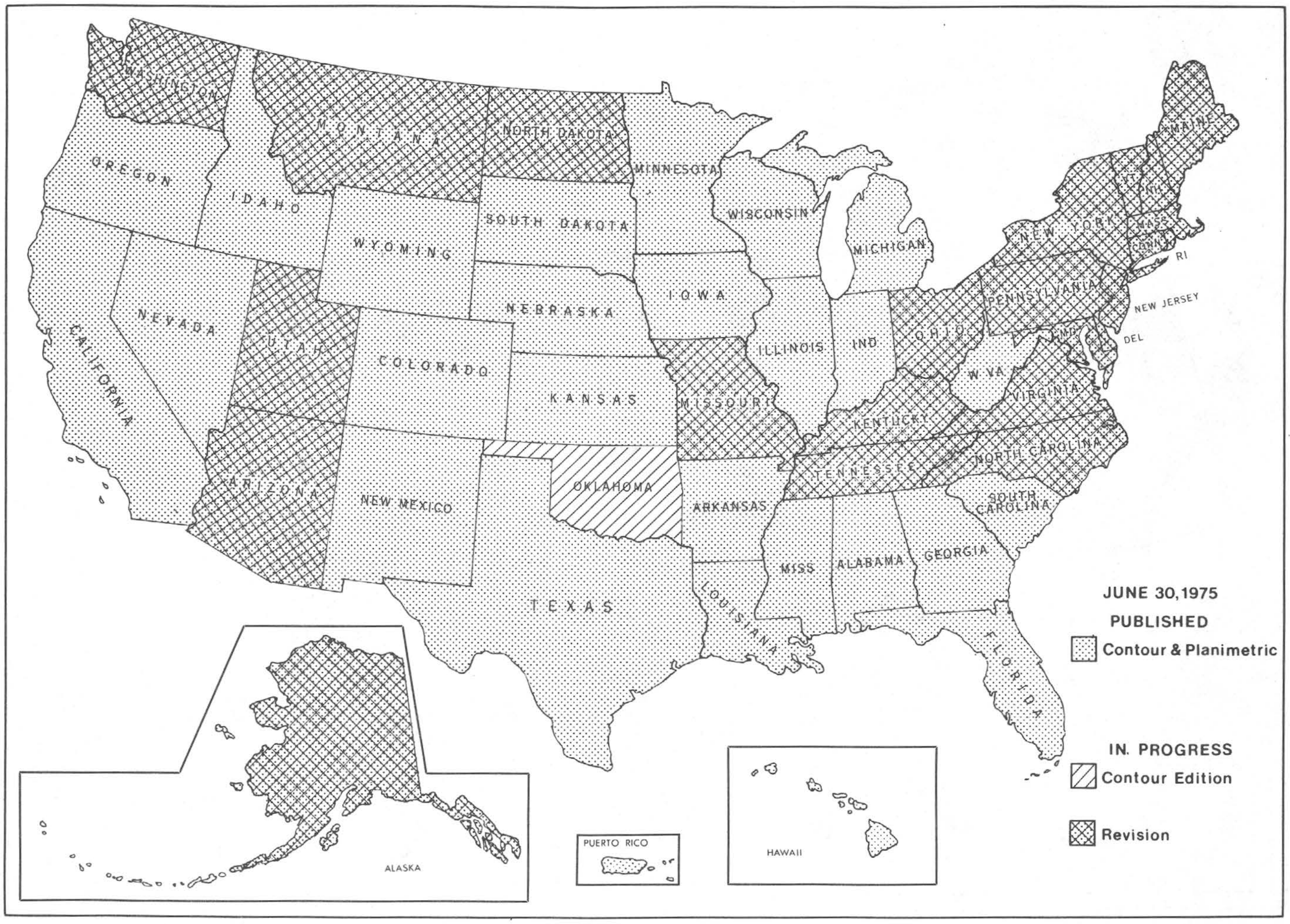


FIGURE 9.—Status of State base maps.

Small-scale map series

The International Map of the World (IMW) series at a scale of 1:1,000,000 is part of an international program to attain worldwide coverage at a uniform scale and format. The maps are published in accordance with technical agreements and specifications adopted at U.N. conferences in 1962 and 1964.

Thirty of the 54 IMW maps required to cover the conterminous United States and Hawaii have been published. Twenty-one additional maps of the conterminous States and 13 maps of Alaska were published by the Defense Mapping Agency Topographic Center from 1955 to 1959 in a military series at a 1:1,000,000 scale. Although these maps do not meet the IMW specifications in all respects, they are recognized by the U.N. Cartographic Office as provisional editions in the IMW series (fig. 10).

Work in progress includes three new maps—Andreanoff Islands, Cold Bay, and Blue Ridge—and four revisions—Cascade Range, Hudson River, Lake Erie, and Savannah. Four maps have been published since June 30, 1974—Des Moines, Ozark Mountains, Hawaii, and Attu Islands.

Orthophotographic products

Orthophotoquads are black-and-white photoimage maps in 7½-min-quadrangle format with little or no cartographic treatment. There is increasing demand for this product, either as an interim map in areas unmapped at 1:24,000 scale or as a companion product to a published line map. The goal for 1978 is orthophotoquads for all areas of the conterminous United States that are unmapped at 1:24,000 scale. Orthophotoquads are also being prepared under cost-sharing agreements with the Soil Conservation Service, the Forest Service, the Bureau of Indian Affairs, and the Bureau of Land Management and under cooperative programs with several States. Approximately 4,000 orthophotoquads were prepared by the

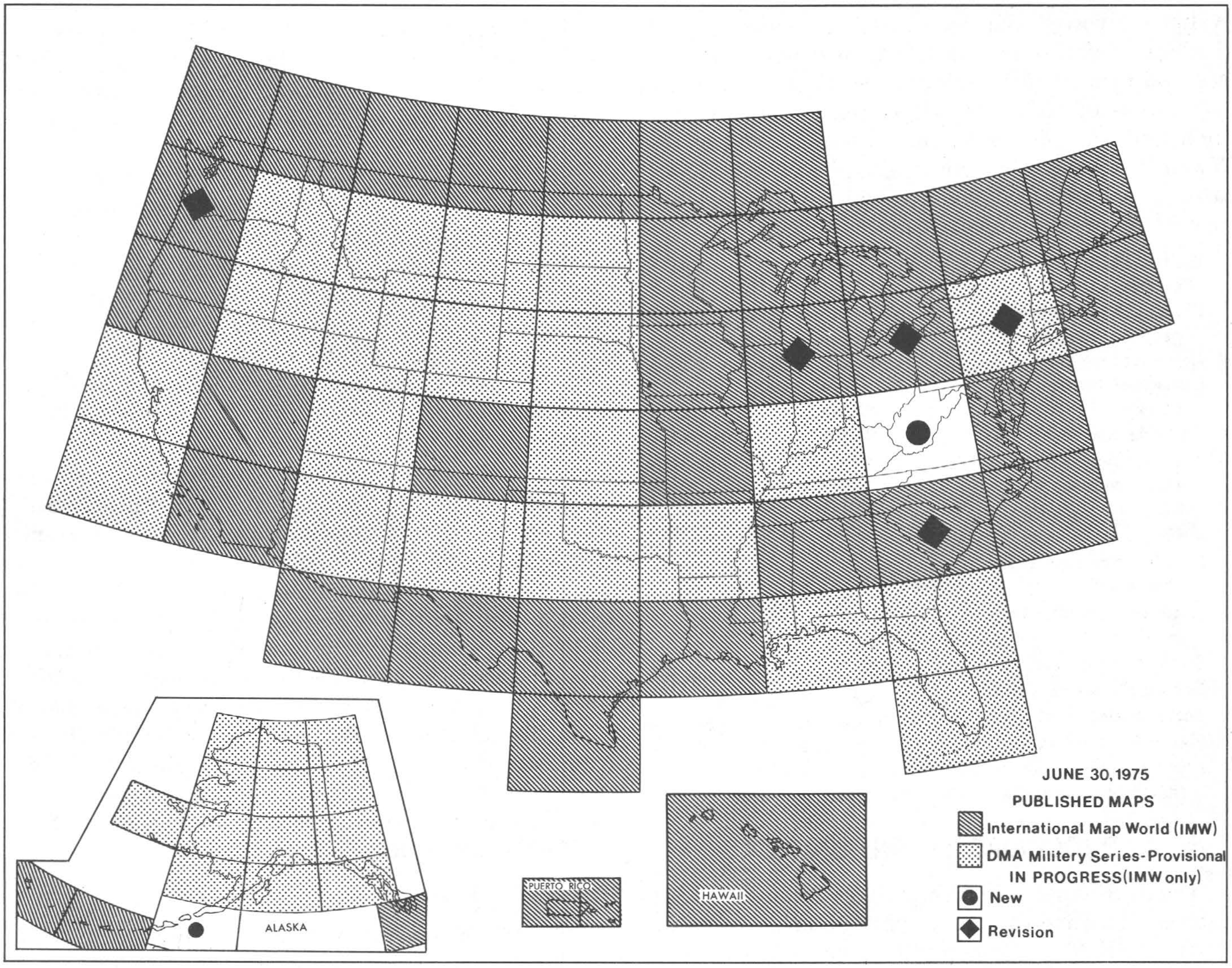


FIGURE 10.—Status of publication of 1:1,000,000-scale topographic maps. Work in progress is being done by the USGS.

USGS in fiscal year 1975; 10 percent of these will be lithoprinted, depending on projected distribution, and the remainder will be reproduced by the diazo process.

Orthophotomaps are color photoimage maps with substantial cartographic treatment that have become the standard 7½-min maps for certain areas of the country where conventional topographic maps cannot adequately portray featureless terrain. The swamps of the Florida Everglades, the lake region of northern Minnesota, and coastal areas of Louisiana and Georgia are major orthophotomapping projects. About 300 orthophotomaps are in the current program.

Intermediate-scale map series

The need for map products between the 1:24,000- and 1:250,000-scale series led to an intermediate-scale mapping program. Its goal is complete national coverage with 1:100,000-scale topographic quadrangles and selected coverage with 1:50,000- and 1:100,000-scale county maps. Agreements with Federal and State agencies provide for the USGS to produce 195 30×60-min quadrangle maps at 1:100,000 scale. Agreements for county maps include 62 at 1:50,000 scale and 121 at 1:100,000 scale; a uniform scale will be maintained within a State.

NATIONAL ATLAS

The National Atlas of the United States of America, published in 1971, was compiled as a reference and research tool for use by public officials, business and industrial organizations, libraries, educational institutions, and scholars who seek information about the United States. Preparation of the 431-page

volume involved the cooperation of more than 80 Federal agencies and bureaus, organizations, commercial firms, and individual specialists. It contains 336 pages of multicolor maps and related information and an index with more than 41,000 entries. Twenty-eight new or revised separate sales sheets are in preparation. The following individual map sheets are available as separate sales items:

- United States general reference
- Physiography and physiographic divisions
- Land-surface form
- Classes of land-surface form
- Tectonic features (Alaska)
- Tectonic features (conterminous United States)
- Geology
- Monthly average temperature
- Monthly minimum temperature
- Surface water
- Principal uses of water
- Territorial growth
- Major forest types
- Annual sunshine, evaporation, and solar radiation
- Distribution of principal kinds of soils: orders, suborders, and great groups
- Potential natural vegetation of Alaska and Hawaii
- Potential natural vegetation (conterminous United States)
- Population distribution, urban and rural: 1960, 1970
- Federal lands
- Population trends: changes, density, and urban-rural
- Congressional districts for the 91st Congress
- Shaded relief (conterminous United States)
- Shaded relief (Alaska)
- Monthly sunshine

PROGRAMS IN ANTARCTICA

The U.S. Antarctic Research Program is administered and funded by the Office of Polar Programs of the NSF. The USGS participates in this program by administering the field-mapping operations, winterover Doppler research programs, and the cartographic programs.

Field operations

During the austral summer, R. D. Worcester and M. C. Crutcher established precise positions by Geoceiver observations at selected strain-rate sites in support of the Ross Ice Shelf Project. The USGS participated for the second year in the University of Nebraska's Antarctic program for measuring ice thickness, movement, and structure over several years.

E. G. Schirmacher and A. I. Malva-Gomes established control for the Lindsey Islands map during the Pine Island Bay expedition, which had been postponed from the previous summer. The ship returning the men to Palmer Station encountered hazardous ice conditions for a few days off the coast of Thurston Island.

W. M. Voight conducted Doppler observations during the austral summer to establish positions at Byrd Station and Siple Station, on the polar plateau at Dome Charlie, and around McMurdo Station. Several LC–130 cargo planes were damaged during support operations at Dome Charlie, but no one was injured.

The two year-round projects conducted at Casey and South Pole Stations continued. Experiments at both sites are supporting ice movement, scintillation, and polar-motion studies with Doppler satellite observations. R. J. Neff is wintering over at Casey Station, having relieved D. L. Schneider. Neff operates the Geoceiver on inland traverses with the Australian field survey parties to support the International Antarctic Glaciological Program.

R. G. Boschert and J. E. Sörensen relieved M. Y. Ellis and T. K. Meunier at the South Pole Station. A year-round Doppler satellite base tracking station is operated by USGS personnel. Results based on several years of Doppler data collected at Pole Station indicate that the ice is moving approximately 9 to 10 m/yr in the direction N. 43° W. New Pole Station, first occupied this year, was located so that it will eventually drift over the geographic South Pole. The abandoned Pole Station was originally located about 830 m downstream from the pole and is now 1,000 m downstream. The men are also monitoring the seismological equipment for the USGS Office of Earthquake Studies.

Cartographic activities

In accordance with Resolution 3 of the Third Meeting of the Scientific Committee on Antarctic Research (SCAR) Working Group on Geodesy and Cartography, the USGS continues to supply published materials and maps of Antarctica to SCAR member nations. A collection of maps and related materials from SCAR members are available through the Antarctic SCAR Library at the NCIC (National Center, STOP 507, Reston, Va. 22092).

The status of USGS mapping in Antarctica is shown in figure 11. Compilation continues on 12 1:250,000-scale maps of the coast of Marie Byrd Land and on a 1:500,000-scale sketch map of Palmer Land at the base of the Antarctic Peninsula. Several 1:250,000-scale maps were approved for printing, but the publication date has not been set. A special large-scale map of McMurdo Station is being prepared with both metric and conventional units for use by contractors in planning utilities and other construction.

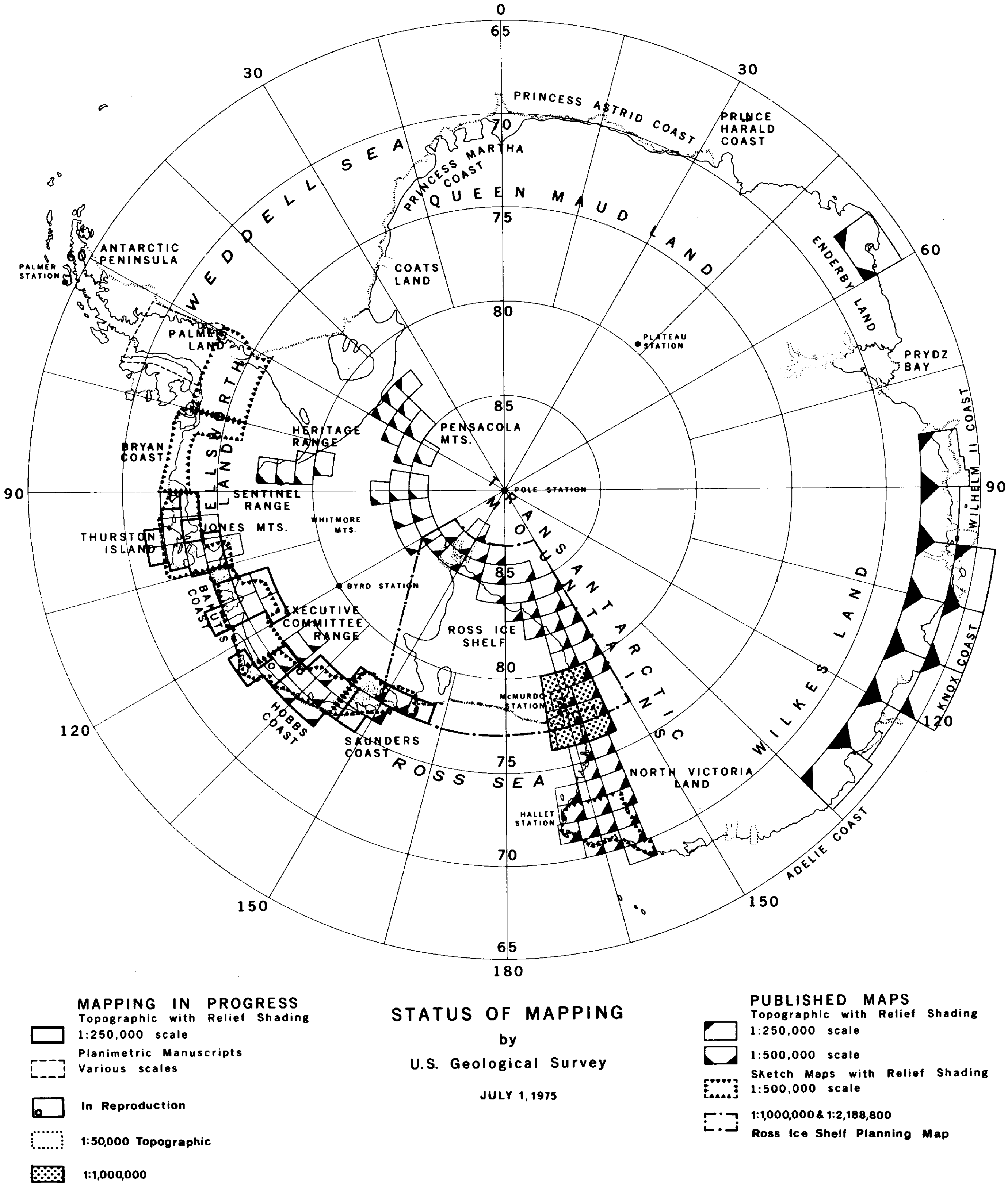


FIGURE 11.—Index map of Antarctica, showing status of topographic mapping.

LANDSAT experiments

Investigations continue under the NASA-funded project SR–149, "The Cartographic Applications of LANDSAT Imagery in Polar Regions." Several map products were completed during this period: a companion 1:1,000,000-scale IMW mosaic of the McMurdo Sound region; 1:1,000,000-scale mosaics of Victoria Land and of the Thurston Island-Jones Mountains area; a single-scene map at 1:500,000 and 1:250,000 scales of the Dry Valley region; and a 1:500,000-scale mosaic of the Ellsworth Mountains.

LANDSAT images are being used to revise 1:250,000-scale maps and the 1:10,000,000-scale map of Antarctica published by the National Geographic Society. LANDSAT imagery has also proved valuable in monitoring the movements of large icebergs and ice islands and the seasonal changes in ice fronts associated with Antarctic ice shelves and in the icepack that surrounds the continent.

INTERNATIONAL COOPERATION

Mexico

The first product of the USGS-CETENAL (Comisión de Estudios del Territorio Nacional) agreement for the exchange of information was viewed at a joint meeting in Mexico City in July 1974. The 1:50,000-scale metric topographic map of the Rio Grande Valley marks the beginning of joint mapping of U.S.-Mexico border areas. Another USGS-CETENAL meeting was held in February 1975 in Menlo Park, Calif., to discuss aerial photography, geodetic control, and exchange of map products.

Pan American Institute of Geography and History (PAIGH)

The USGS continued to provide administrative and staff support for the U.S. member of the Commission on Cartography and for the chairman and U.S. member of the Committee on Topographic Maps and Aerophotogrammetry. Six USGS personnel are contributing to PAIGH activities.

The U.S. section of the Commission on Cartography and the chairman of the U.S. National Section held two meetings in Reston, Va., during the fiscal year. In September 1974, they met to discuss the results of the fifteenth meeting of the Directing Council held in Mexico City. In March 1975, they met to consider actions taken by the authorities of PAIGH at Caracas, Venezuela, regarding new projects and programs of the various commissions.

Color separates for the "Atlas of Volcanic Phenomena" were delivered in July 1974 to the PAIGH Secretary General in Mexico City. The atlas is an active sales item in the United States, and PAIGH plans to publish a Spanish edition for distribution throughout Latin America.

Saudi Arabia

The USGS is continuing to assist the Ministry of Petroleum and Mineral Resources of the Kingdom of Saudi Arabia in its effort to increase the permanent capacity for geological and resource investigations and to direct the mining industry toward the best possibilities for mineral exploration and development. The fourth extension agreement with the Ministry was completed in June 1975 and approved by the Director of the USGS. The agreement, covering a 3-yr period starting July 10, 1975, was forwarded to the Ministry for approval. In support of this program, the USGS continues to assign personnel to Saudi Arabia. In the latter part of 1974, R. C. Nixon replaced K. S. McLean as a field surveys specialist, and C. M. Robins replaced F. G. Lavery as a photogrammetric specialist.

RESEARCH AND DEVELOPMENT

FIELD SURVEYS

Inertial surveying

After more than 16,000 km of trial surveying by the Defense Mapping Agency (DMA) with the Jeep-mounted Position and Azimuth Determining System (PADS), several government agencies recognized that, by applying the system in closed traverses, PADS can probably establish positions accurate enough for public-land and map-control surveys. Such applications are intended for the Auto-Surveyor, a civilian version of PADS being developed by Litton Systems, Inc., for the Bureau of Land Management (BLM). The Auto-Surveyor consists of an inertial measuring unit, a digital processing unit, a control and display unit, a power supply unit, and a cassette recorder. With a battery and electrical cables, the system weighs 150 kg and fills the passenger space, behind the pilot and operator, of an FH–1100 helicopter.

The innovation that makes an inertial navigation system perform so accurately is the development of the zero-velocity update procedure. The vehicle is periodically brought to a standstill, and the system automatically levels the platform to the local gravity vector and analyzes the residual velocity values to obtain correction terms. As the traverse continues,

with periodic zero-velocity updates, the computer accumulates information about and compensates for systematic observational errors and the systematic changes in the gravity field. Less accurate results are obtained when the line has an abrupt change in direction, such as a right-angle turn.

The accuracy of the Auto-Surveyor in a flat desert environment (near Phoenix, Ariz.) was tested in December 1974 by the BLM. A major part of the test was trying different combinations of procedures, 3- or 5-min periods between landing or hovering updates, over straight survey lines about 38 km long. A preliminary evaluation of test data indicates a high level of accuracy—standard deviations of 0.74, 0.71, and 1.00 m in latitude, longitude, and elevation, respectively—and significantly improved accuracy with 3-min updates. To obtain accuracies suitable for map control, lines must be nearly straight, no longer than 50 km, and double run. The average travel time for one 38-km run was 30 min. Some developmental work is needed to extract the highest accuracy obtainable with the present hardware. For USGS use, improved accuracy in vertical measurements is necessary before the Auto-Surveyor can be applied with full practicality.

A system that will provide ground profiles by measurement from an aircraft, the Aerial Profiling of Terrain System (APTS), is being developed by the USGS and the Charles Stark Draper Laboratory, Cambridge, Mass. The proposed APTS, to be carried by a light single- or twin-engine plane, comprises: (1) An inertial measuring unit to continuously determine latitude, longitude, and elevation of the aircraft; (2) a laser tracker unit to measure on positioned ground retroreflectors for periodic updating of the inertial system; (3) an imaging instrument (TV or camera) to record the flight path; (4) a computer to process and adjust the measurements and to provide in-flight guidance; and (5) a tape recorder to store the profile data. The terrain profiling system in operation is visualized as a powerful tool for flood studies as well as for map-control surveys.

Geodetic data management agreement

The NOAA-USGS Memorandum of Understanding of June 13, 1974, established joint policies and procedures for the exchange, maintenance, and distribution of geodetic control data. That agreement reaffirms the mandate of the Federal Mapping Task Force to establish a central file of geodetic data and thus will improve service to the user by recognizing the National Geodetic Survey Information Center (NGSIC) as the primary source for Federal geodetic control data. The USGS is committed to transferring all the geodetic data that it has acquired to NGSIC by 1980. By this agreement, the USGS will provide data on monumented, recoverable control points of third-order accuracy or better that are connected to the National Horizontal and Vertical Control Networks in a computer-compatible form specified by the National Geodetic Survey (NGS).

To date, only the software for handling horizontal control has been developed by the NGS. Present plans are based on the 30-min quadrangle as the basic unit area for storage and retrieval of data. The USGS is modifying the NGS horizontal adjustment program for use in preliminary evaluation of the data. The NGS wants a good elevation on every horizontal station, based on whatever data the USGS can supply, including elevations scaled from published maps. In contrast to horizontal control, even doubtful vertical data are desired because repetitive leveling is increasingly important in identifying and quantifying surficial movement. USGS mapping centers have undertaken pilot projects to discover problems, solutions, and best methods. The NCIC is maintaining files and supplying data on request during the transfer period and warning against the use of old USGS marks (not considered of third-order accuracy and therefore not transfered to NGS responsibility) for extending geodetic control. Also, the NCIC is investigating ways and means of developing a system to store, retrieve, and supply photogrammetric control along with pertinent images.

Equipment improvements

Ground verification of mapworthy features is an essential but painstaking and costly phase of topographic mapping. In an effort to streamline these field operations, a windowed van was custom fitted to provide a comfortable and well-equipped mobile work station. The vehicle is a ¾-ton upgraded Chevy Van with a wide sliding door on the side and double doors at the rear. Sitting about 0.5 m higher than the average car, the van affords a better view of the terrain. The basic work station is a cut-down drafting table with a built-in light box and drawers for supplies, photographs, maps, and fieldsheets. The desk chair is mounted on rails, with a variable-position locking device. Special brackets inside and outside the van conveniently store stadia rods, planetables, and tools. First field trials of the custom van won immediate approval, largely because on-the-spot scribing is particularly helpful in revision surveys and in annotating orthophoto bases.

Two USGS liquid-damped and two Keuffel and Esser air-damped alidades were modified for mounting directly on tripods. With the proper tripod, an instrument height of about 2 m is possible. Tangent screws were added to provide smooth slow motion in the horizontal direction. Also, the optics of the Keuffel and Esser alidade were modified so that the scale-reading eyepiece is located beside the main telescope. The increased instrument height provided by tripod mounting raises the line of sight, and the effect of heat waves is lessened. The instrumentman can take readings from an erect position rather than a stooping position. In use, the tripod alidade significantly improves the efficiency of surveys for supplemental vertical control while it maintains specified accuracy.

Special surveys and investigations

Monumentation and leveling observations were completed on a test course established around the National Center at Reston, Va. Eighteen stations were set and leveled over, including one in the lobby and one at the flagpole. During the year, the course was used for evaluating several new instruments as well as for training employees. Horizontal positions will be established on the course this year. In addition, a station (Powell) has been set on the roof of the National Center and will soon be tied into the NGS triangulation network.

In five cases of boundary disputes (portions of the Maine-New Hampshire boundary; the Dorchester County-Wicomico County, Md., boundary; the Shenandoah National Park, Va., boundary; the Everglades National Park, Fla., boundary; and the Louisiana-Texas boundary), mapping expertise was called on to supply surveyed positions or traverses, maps, and court testimony.

Releveling in the Isleton, Calif., delta area indicated an average of 6 to 9 cm subsidence with some localized sinking of more than 30 cm since 1967. In contrast, a low range of hills on the western edge of the delta showed an uplift of 3 to 6 cm. A network of new leveling and releveling was completed in the Raft River Valley, Idaho, to serve as a monitor network for the study of vertical crustal movement. The valley is a fertile agricultural area where ground water is being used for irrigation; it is also a potential geothermal area. The releveled bench marks revealed that up to 80 cm of subsidence has occurred in the central part of the valley since 1958.

To monitor and control saline-water pumping for mineral extraction at Searles Lake, Calif., a monitor level network was recently established for the Conservation Division. Local crustal changes were indicated in at least two separate areas around the lake. Fifteen monitor level lines have now been established across a number of western fault zones to measure vertical movement. The releveling of the Fairview Peak, Nev., monitor line showed vertical creep of as much as 4 cm in a 1-yr period.

PHOTOGRAMMETRY

Digital photogrammetry

The computer industry is offering increasingly flexible software and hardware at a small fraction of the cost a decade ago, a circumstance having considerable effect on all aspects of civilian mapping. Through digital techniques, it is conceivable that, with a minimum of effort, mapmakers will be able to respond to users' needs in a matter of hours or days rather than years.

The goal is to produce maps digitally at any scale and in a variety of formats. To do so, cartographic data must be converted to numerical data in machine-readable form. A single topographic quadrangle map contains more than 100 million discrete bits of information, so that creating a digital map data bank is formidably complex. Also, the data bank must be designed to connect with other geographically related information and management systems.

With the assistance of the Rome Air Development Center (RADC), Griffiss Air Force Base, N.Y., the USGS conducted a pilot project to discover problems in digitization—both deriving digital map data from the stereomodel and generating graphics from the data. The AS–11B–1 analytical plotter was used to extract digital planimetric and terrain data from unconventional source material for the Estrella SW, Ariz., quadrangle. An interactive system allowed automatic plotting from magnetic tape with the Cartographic Digitizing Plotter, fast manual editing with disk storage, and automatic tape correcting. Additional smoothing of the data will be done automatically with RADC's Batch Processing System. When data editing is completed, the updated tape will be used to drive a first-order plotter and produce the finish-quality color-separation negatives.

Map control from superwide-angle photographs

High-altitude superwide-angle photographs can be used to provide pass points for wide-angle mapping photographs and thereby reduce the amount of vertical ground control needed. Early tests with 3,350- and 6,700-m superwide-angle photographs failed to meet vertical accuracy requirements and indicated unsatisfactory point transfer. In a third trial with

the 6,700-m photographs, acceptable results were achieved after test procedures were changed: All untargeted points were drilled on the diapositive plates; four readings were taken on fiducial and image points, two normal and two with optics rotated 90°; the block was adjusted as a whole; new camera calibration data were used (made possible by improvements in the USGS camera calibrator); radial lens distortion was corrected by a newly devised grid method; and independent affine transformations to the calibrated fiducial mark coordinates were made for each day's measurements. The resultant rms residuals were 1.1 m (3.6 ft) horizontally and 0.5 m (1.6 ft) vertically. The 1:24,000-scale topographic maps are now being compiled by using the photocontrol established by the refined solution.

Map control from high-altitude photographs

A study is underway to assess the practicality of using high-altitude quad-centered photographs and semianalytical aerotriangulation to establish vertical control for normal production compilation with low-altitude photographs. Horizontal and vertical control points, previously selected on low-altitude photographs, were pinpricked on quad-centered 12,000-m photographs of the La Gloria, Tex., quadrangle and 10,800-m photographs of the Gillette, Wyo., quadrangle. Observed x, y, and z coordinates of all points were measured with a C5 Stereoplanigraph and adjusted by four versions of a semianalytical aerotriangulation program that treat the error surface in turn as a plane, a sphere, a spheroid, and a cylinder; 50 to 60 vertical control points are available in each quadrangle so that dispersion patterns could be chosen for each assumed error surface.

The adjustments were first computed with all known elevations treated as control. Then only known elevations for the selected control patterns were used as control in the second series of adjustments, and the rest of the points were used as test points. The object was to find the error surface most closely approximating the intrinsic errors of the stereomodel. The lowest residuals were obtained from the adjustment based on a spheroidal error surface; for both study areas, rms residuals were less than 1.52 m (5.0 ft) at control points and averaged 1.60 m (5.25 ft) at test points. The error surfaces were plotted with the Calcomp General Purpose Contouring Program and Perspective Drawing Software System (Three-D). The graphic displays enabled easy detection of major errors in original elevation data.

Aerotriangulation of quad-centered photographs

The stepped-up production of orthophotoquads calls for the aerotriangulation of hundreds of quad-centered photographs each month. The unique grid of camera positions allows a minimum of pass points to serve many purposes—as model and flight ties and as orthophoto scaling points. All points and point transfers to the scanning plates are marked with a Wild PUG. An efficient and accurate adjustment is the simultaneous block adjustment of models, averaging 2 s of central processing unit (CPU) time per model on the IBM 370/155 computer. A fully analytical adjustment of refined comparator measurements averaged 8 s of CPU time per plate. With either mode, the rms horizontal errors of test points varied from 1.5 to 3 m (5 to 10 ft).

Compilation from large-scale maps

A test was conducted to find out if large-scale engineering plans can be efficiently incorporated into standard 1:24,000-scale maps. A film positive of a 1:2,400-scale engineering plan of a portion of Lewiston, Maine, was reduced to 1:24,000 and projected at 1:4,800 in a Kelsh plotter. Map detail was traced monoscopically and reduced to 1:24,000 through a pantograph. Difficulties were encountered in extracting the desired information because of the lack of culture classification on the large-scale plans and the fine detail of the contours, which had to be generalized for 1:24,000 portrayal. For comparison, a stereomodel of the Lewiston area, which covered about 2.5 times the test area, was compiled by standard methods in about the same time required for the monoscopic plot. On the basis of compilation tests and limited field checking, large-scale engineering plans cannot be used to advantage in compiling 1:24,000 topographic maps.

Model orientation with pocket calculators

Pocket-size programable calculators are being applied to model orientation with optical-train stereoplotters. For the relative orientation of models during semianalytical aerotriangulation with a Wild A 7 or Kern PG 2, the analytical procedure requires only one or two iterations, in comparison with the two to six normally required. The technique is particularly helpful for setting up stereomodels with rugged terrain or large tilts. With camera orientation data from fully analytical aerotriangulation, the calculator is programed to compute the Wild B 8 settings for relative and absolute orientations. The resulting stereomodels are correctly scaled, nearly clear of y parallax, and nearly level.

Large-scale planimetric mapping

A large-scale (1 cm=24 m) planimetric map was produced with the Kelsh stereoplotter. The area of approximately 2.6 km^2 (1 mi^2) was compiled from materials and control data acquired previously for the Fort Wayne, Ind., large-scale orthophoto project. The photographs were taken with a 152-mm f.l. camera from 1,400 m. The manuscript was compiled at model scale on a plotter with an optimum projection distance of 525 mm. Contours were not compiled, but, given standard-accuracy supplemental vertical control, 5-ft contours could be compiled easily. Copies of the experimental map are being evaluated by the Topographic Division and Fort Wayne officials.

Correcting radial lens distortion

A new method of correcting for radial lens distortion was devised, in which corrections are applied according to the grid location of the point rather than the radial distance from the point of autocollimation. This method provides corrections for asymmetrical and irregular distortions and for nonflatness of the magazine platen.

The data for the corrections are obtained by measuring collimator images on a series of film exposures made with the camera on the calibrator at various orientations. The distortions, or differences between measured and true (calibrated) positions of the collimator images, are computer converted to contour form. Then a distortion grid is derived from the math model, typically a 5-mm grid for a 23-cm square format. The x, y correction for a given point is determined by interpolation between nearest grid coordinates.

Automatic image correlation

A study was completed on the evaluation of density factors causing difficulties in the automatic correlation of stereoimages. Transparencies of a low-altitude stereopair were scanned with a Joyce-Loebl microdensitometer, and the density profiles were mathematically and visually compared. Density peaks were visually correlated wherever possible along corresponding density profiles. An arbitrary origin was chosen (where parallax was zero), and distances of peaks from the origin were measured with the Bendix DataGrid digitizer; the differences in measurements for matched peaks represented parallax differences and were later used to calculate elevation differences for constructing profiles.

The results indicate that many factors contribute to losses of automatic correlation. The easily detectable difficulties are attributed to:

1. Objects that appear in only one photograph, like the side of a building.
2. Large objects obstructing small objects on only one photograph.
3. Sitautions in which a series of density peaks represent density changes rather than changes in elevation.

Other possible causes of difficulties are:

4. Slope of terrain.
5. Correlation of leafless trees with their shadows.
6. Problems with electrical noise when the signal-to-noise ratio is low (i.e., very little density variation in the photograph), as in snow-covered or heavily forested areas.
7. Objects that equal the scanning-spot size in one photograph and are smaller than the spot size in the other photograph and thereby produce different density patterns.
8. Effect of light intensity on density variation. The center of one photograph corresponds to the edge of the adjacent photograph, and, as a result, the density variation is larger in one profile than in the other.

Panel photography by helicopter

A Hasselblad 70-mm camera installed in the chin of each USGS helicopter is being used to obtain improved panel photographs. Since paneling rarely can be timed for the panels to show on the mapping photographs used for aerotriangulation, each panel must be photographed from a small aircraft so that the surrounding ground features can be related to those on the mapping photographs. The helicopter installation was designed to obtain a vertical photograph having a relatively large format and a scale that can be matched with that of the mapping photographs. The pilot makes his run over the panel in a cardinal direction if possible and usually 600 to 900 m above terrain. Two frames are exposed for each panel to yield a stereopair. In the field, a system of leapfrogging the paneled points allows the pilot to fly without passengers on one trip over any given panel and thus makes it easy to climb to the required altitude. The saving is in taking panel photographs while the crew is on the spot, particularly when it is necessary to take up the panel materials afterwards, as it is in wilderness and other controlled areas. The helicopter system is producing photographs that make identification and correlation of paneled points easier and cheaper than in the past.

CARTOGRAPHY

San Juan's new metric map

The standard topographic maps of Puerto Rico and the Virgin Islands are a mixture of 7½-min quadrangles at 1:20,000 scale with metric contours and 7½×6-min quadrangles at 1:24,000 scale with contours in feet. The Puerto Rico maps measure 74×81 cm on the average, and thus only one can be printed in a press run. As the maps are in need of extensive revision, it was proposed to reformat all Puerto Rico and Virgin Islands maps at 1:20,000 scale in 45×60-cm quadrangles (representing a ground area of 9×12 km), a design which would enable printing four at a time on the large five-color Harris press. With other improvements in symbols and portrayal, the new series would represent another step toward promoting simplicity and economy for future maps.

Rather than map Puerto Rico in the extremities of UTM zones 19 and 20, a UTM zone 19.5 was established (central meridian at 66° longitude) for the proposed series. The San Juan area was selected for the experimental map because of its wide variety of mapped features, although 1969 field data had to be used. The grid format was constructed by a combination of automatic plotting and hand plotting. Archival negatives were reproduced and feature separated as well as color separated. Many new symbols and line weights were used that simplify drafting and lend themselves to digitizing (for example, dots were eliminated from spot and linear symbols). Only two type styles (Souvenir and Univers) served both the body and the margin of the map. The reproduction negatives were prepared by using mezzotint screens to subdue or enhance features and to obtain good color combinations. The maps were printed four up on 44×54-in paper and are being distributed for evaluation.

Five-color interim revision maps

Interim-revision maps, constituting over 15 percent of the USGS line maps prepared annually, are normally printed in the five standard map colors plus purple for added features. Printing in six colors is inefficient with the new five-color press, since an additional impression on another press is required. Color schemes must be designed that will produce the full range of map colors with no more than five impressions.

To determine the feasibility of a five-color scheme for interim-revision maps, the North Miami, Fla., 7½-min map was first contact photoprinted from normal color-separation materials in the three primary colors—yellow, magenta, and cyan—plus black and brown. Random-pattern mezzotint density screens were used to blend colors and obtain desired variations in the basic colors. The second experimental printing was prepared by using biangle screens and 120-line-screen tints with the five combined reproduction negatives to achieve the desired effect. The cost advantage of the five-color printing scheme ranges from $244 per map printed on a two-color press to $64 per map printed on a five-color press plus a two-color press for the additional color. In addition, turnaround time in the plant is improved 2.5 times by printing interim-revision maps in five colors rather than six colors with three passes through two-color presses.

Land-use map overlays

Methods and formats for classifying and delineating land use are still under investigation. Personnel in USGS mapping centers have been trained in the compilation of land-use lines, and several experimental projects were started. One approach is to compile land-use information at 1:125,000 scale, which will be reduced to 1:250,000 scale and registered with the standard map base and other boundary overlays. Level II (Anderson and others, in press) classification for quadrangles in Virginia and Florida is in progress. Level III classification will be attempted at 1:24,000 scale for 12 7½-min quadrangles in the Atlanta, Ga., area. In another project, land-use information was compiled stereoscopically and monoscopically at scales of 1:160,000 and 1:125,000 for quadrangles in Arkansas.

An overlay, "Level I Land Use and Land Cover Classification," was prepared for the 1973 Henderson, Tex., 7½-min quadrangle map. Five categories are shown: urban and built-up land in light magenta, agricultural land in yellow, forest land in green, water in blue, and wetland in grey tint with swamp symbol. The overlay was contract printed on clear polyester film, which gives good transparency and register. This type of overlay is being considered for displaying land status and ownership, terrain slope, and additional themes for the National Atlas.

Flood-plain maps

Sixteen watershed areas in St. Louis County, Mo., are being mapped as a joint venture with the Water Resources Division (WRD) for the HUD flood-insurance program. The project comprises 24 maps at 1:6,000 scale, which will be a combination of orthophotoimagery and linework. The flood-prone areas will be contoured at 3-ft intervals from 1,200-m

photographs. Profiles compiled at small intervals will be used by the WRD to compute probable flood levels, which will also be delineated on the maps.

50-State map

In response to many requests over the past few years to graphically portray the 50 States of the United States in correct proportion, position, and relationship to one another, a 1:6,000,000-scale map of the 50 States was prepared. The projection is a wide-band Lambert conformal conic with standard parallels at 37° and 65°. Highways, rivers, boundaries, railroads, cities, towns, and names were compiled from the National Atlas general reference map (1:7,500,000) and global navigation charts (1:5,000,000) and at two levels of content so that maps at smaller scales can be derived. The map can also serve as a base for future thematic editions. The five-color 50-State map measures 92×144 cm (36×56.6 in) and can be purchased from USGS map sales offices.

Slope maps

Another method has evolved for making slope maps. The contour negative is not projected but is secured to a stationary glass above and in light contact with film on an orbiting table. Exposure is made with a remote pinpoint light source. There are several advantages to this method: (1) The contour negative is not reduced, (2) the film and contour negative (or spread positive) are stud registered rather than visually registered, (3) the precision in line spreading and choking is greater, (4) the tendency to fog with very wide chokes is diminished, and (5) light intensity is greater, particularly important with the broader spreads and chokes.

1:100,000-scale maps

Several experimental projects are underway to produce samples of 1:100,000-scale topographic maps. The Healdsburg, Calif., map (northeast quarter of the 1:250,000 Santa Rosa map) was prepared partly by enlarging the 1:125,000 San Francisco Bay region maps and updating on the basis of 1972 U–2 high-altitude photographs; eight 7½-min quadrangles, reduced and mosaicked, completed the map. Color-separation plates were designed for flexible reproduction; the contours and land lines were scribed without breaks to facilitate digitizing. Metric equivalents are shown in red for all spot elevations.

The Watford City, N. Dak., map (southeast quarter of the 1:250,000 Watford City map) is in preparation. The 32 7½-min quadrangles covering the area were reduced to 1:100,000 scale and mosaicked. Metric contours will be interpolated.

Digital cartography

Converting cartographic data—point, linear, and areal—to digital data can be approached in several ways. Experiments started last year in contour digitizing by automated line-following proved the capability of the i/o Metrics Sweepnik digitizer. A computer-controlled laser beam digitized land-use boundaries at 1:24,000 scale from four experimental Fredericksburg, Va., overlays, with readings recorded every 250 μm (the instrument is capable of 5-μm increments). The same device is also used to plot from digital data by exposing film with the laser. More experiments with the Sweepnik are in progress, including the compilation of additional land-use plates at scales of 1:125,000 and 1:250,000 for the Land-Use Data and Analysis program and contour and drainage plates at 1:24,000 scale for the Geologic Division coal resources program.

Preliminary feasibility studies with digitizers that scan with a photodiode linear array (pushbroom) show promise for highly automated cartographic applications. As the pushbroom scans the line copy, the intersections (line positions) are recorded. The advantages of this type of device over the line-following device are (1) three to four times faster digitization of a quadrangle; (2) virtually automatic operation (a line-follower requires an attendant to insure continuous operation); (3) batch-process computer editing rather than interactive manual editing; and (4) draft-quality copy input rather than finish-quality input.

The USGS recently purchased a computer-controlled automated drafting system (model 1232) from Gerber Scientific Instruments, Hartford, Conn. The system offers high-precision (25 μm) low-speed drafting (up to 9.5 cm/s) and the capability of inking or scribing on a drafting surface or exposing on photographic film. The plotter is controlled by a Hewlett-Packard 2100A minicomputer. The 1.2×1.5-m (4×5 ft) flatbed easily handles extra-large base sheets for State and regional maps. The system is now producing high-accuracy grids for hardware calibration, low-frequency gratings for generating orthophotos, line screens for cartographic and printing applications, and computer-generated projections for special projects. Examples are the Albers equal-area and Lambert conformal conic projections of offshore areas under study by the Geologic Division, plotted from control and data tapes generated by Version IV of the Cartographic Automatic Mapping

program now stored on the USGS computer. Computer programs have been written for generating and plotting base sheets and orthophotoquad graticules and grids with the Gerber system.

The digital orthophoto system (DOS) will produce digital profile information from a stereoscopic model, store the information on magnetic tape, and use the information off-line to control the photographic unit that produces the orthophoto. The electronic units are designed with the flexibility to adapt to several types of profiling and exposing units. DOS comprises three subsystems:

1. The prototype of a profiling device is being built to attach to a Kelsh or ER–55 for translating the platen in z and the guide-rail carriage in x, y under servo control. A prototype device for the Kern PG 2 has been tested.
2. The electronic subsystem consists of a profile recording assembly (magnetic tape) now being tested and a playback or scanning assembly.
3. The orthophoto output instrument consists of a projector equipped with a three-axis servo system for off-line exposure of orthophotos.

First tests of the complete system will consist of profiling with a C5 Stereoplanigraph and scanning and exposing with a GZ 1 Orthoprojector.

Orthophoto systems

The USGS is evaluating orthophoto systems for standard quadrangle mapping. Tests with the Gestalt Photo Mapper GPM–2, Galileo-Santoni Ortho Simplex, Wild AVIOPLAN, ICOS, Gigas-Zeiss GZ 1, Danko-Arlington K–320, Wild PP 08, and Jenoptik Orthophot B have been completed. Additional tests are planned with OLOPS at the DMA, the Kern OP 2 Orthoprojector, and the Matra SFOM–910. Steps have been taken to purchase the PP 08, Orthophot B, and GPM–2. A GZ 1 acquired from the DMA will be adapted for off-line scanning under control of a USGS-designated electronic unit. USGS Orthophotoscopes are continually being improved; variable transformers enable more precise light control during exposure, and adhesive is replacing vacuum units for holding the film.

Orthophoto scan masks

Masking techniques were applied to the problem of scan lines on orthophotos. The Gerber plotter was used to construct a 5-mm (scan width) grating, from which two masks were prepared, one having alternating clear and opaque 5-mm bars and the other having the reverse. In orthophoto production, each mask is stud registered over the film; the first exposure is made through the open bars of mask 1, and then the operation is repeated with mask 2 until the entire film is exposed. The fact that the first trial resulted in a simulated orthophoto with uniform-width scan lines suggests that these lines could be eliminated. The next step is to prepare new masks of different dimensions.

Orthophoto image quality

It is desirable to have continuous image tone from one quadrangle to the next throughout an orthophotoquad project. Thus, density levels and ranges for photographic products must be planned in advance for the complete project. Project planning is based on the principle that the output density range and level for each item remain proportional to the same parameters measured on a sample of the input to the system. Achieving tone match between items by project planning may produce one or more orthophotoquads of less-than-satisfactory quality and usability. An example is the effect on low-density-range items in a high-density-range project where item contrast is increased very little or even decreased in the end product. In this situation, a deviation from the project plan is warranted to achieve the more desirable product.

Planning the image quality for orthophotoquad projects has been programed for the computer. An adjustment in contrast is based on a parabolic function derived by the program to fit product specifications. The amount of adjustment varies with the item: the lowest range item receives the largest boost in contrast, and the highest range item receives little or no adjustment. The prototype program is being used by the Western Mapping Center with encouraging results.

Large-scale orthophotographic maps

Four contract urban mapping projects started last year are nearly completed, and large-scale orthophotographic maps will soon be in the hands of users to determine their suitability for dealing with urban problems. The USGS has served as technical advisor and monitor, with the objective of developing standards for urban mapping. The projects are in various stages of completion:

1. Fort Wayne, Ind. (low, rolling topography and 180,000 population)—440 1:2,400-scale orthophotographic maps covering 570 km^2 are completed and being used for city and county projects.

2. Charleston, S.C. (coastal city with relatively flat topography and 75,000 population)—590 1:2,400-scale orthophotographic maps covering 1,080 km² are 80 percent complete.
3. San Francisco, Calif. (coastal city with wide range of topography and 700,000 population)—Orthophotographic maps of 145 km² at 1:6,000 scale and of selected areas at scales of 1:2,400 and 1:1,200 are 85 percent complete.
4. Frederick, Md. (rolling topography with 25,000 population)—64 1:2,400-scale orthophotographic maps of 160 km² are 90 percent complete.

Private mapping firms were further sampled in a project to determine their capabilities for orthophotomapping urban areas with considerable relief. Six firms having different instrumentation prepared five 1:2,400-scale orthophotos from 1,800-m, 153-mm f.l. and 3,600-m, 305-mm f.l. photographs of Ambridge, Pa. (120-m relief), and from 1,200-m, 153-mm f.l. photographs of Jackson, Mo. (30-m relief). The orthophotos were prepared with the Matra SFOM, Zeiss Ortho 3, Kelsh K–320, Jenoptic Orthophot, Gestalt Photo Mapper GPM 1, and Wild PP 08. Each orthophoto was tested for relative accuracy, the difference between orthophoto and stereomodel coordinates at 35 test points. The resulting accuracies were considered acceptable for an orthophoto of rugged terrain, but it was significant that the results did not favor any one firm. The 153-mm photographs produced better resolution than the 305-mm photographs; however, they required more careful scanning. The fact that the orthophotos made from 305-mm photographs had fewer image mismatches in rugged terrain indicates that the angle of projection is more favorable with 305-mm photographs than with 153-mm photographs.

Experimental orthophoto products

Six 1:10,000-scale orthophotoquads of the Sapelo Island research project covering the Doboy Sound, Ga., 7½-min quadrangle were completed. The coastal wetlands were interpreted from color-infrared photographs and classified according to major plant species associations. The annotated orthophotoquads are available as ozalid paper prints.

Two orthophotoquads and companion line maps at 1:125,000 scale are being prepared for the Connecticut Valley urban area study. The 99 7½-min orthophotoquads of the Connecticut Valley will be reduced to a scale of 1:80,000 and mosaicked onto control bases. The mosaics will then be reduced to 1:125,000 scale and combined with the collar. The line maps will be prepared from the State base map for the southern map and from published quadrangle maps for the northern map. The maps will bear minimal name and collar information.

Three experimental color orthophotoquads of the Tioga, N.Y., area were prepared from 1:80,000-scale 153-mm F.L. color photographs. The diapositives were made by Earthsat Corporation, Washington, D.C., and the color orthophotos were made by Geometric Systems, Inc., Kirkwood, N.Y., with the Jenoptic Orthophot. The resulting color balance was poor, characteristic of color film exposed at high altitudes.

Dry Valley, Antarctica, is being mapped with 1:50,000-scale orthophotoquads with 50-m contours. Vast snowfields combined with sharp jagged relief caused loss of the stereoview and unavoidable breaks in the scans. In many photographs, the density range is extremely low but graded across the exposure, so that density matching in mosaicking was nearly impossible. The mosaics of 1:35,000-scale prints were retouched before reduction to 1:50,000 scale.

COMPUTER TECHNOLOGY

With its scientists engaged in research into every existing and potential source of energy, the USGS is increasingly charged with providing direction to both Government and industry in all phases of energy-related exploration, development, and production. Concomitantly, USGS requirements for increased computational capacity accelerated in fiscal year 1975. This growth pattern was typified by a transition from rudimentary batch-processing techniques to more sophisticated interactive processing methods, using time-sharing systems, and the use of database-management software packages. The Computer Center Division (CCD) continued its expansion of computation facilities to meet the needs of the USGS's scientific community. Future expansion was formally addressed in a comprehensive planning document, "The USGS Automatic Data Processing Management Plan," that identified requirements for a 5-yr period (1976–80).

RESTON COMPUTER SYSTEM

During fiscal year 1975, the bulk of USGS batch-processing requirements was met by the IBM 370/155 computer system located in the National Center at Reston, Va. The system accommodated the batch requirements of local users, as well as those of the remote batch-processing sites throughout the United States. Action was taken to acquire and install a second IBM 370/155 when analysis predicted saturation of the single system by July 1975. The two central processing units will be identically configured and possess equal memory capacity (4 million bytes each). The planned configuration will ensure that either processor could execute any current or future program designed to run on the existing system. A software load-leveling technique designed to balance the processing load on each processor is being developed. In case of a processor failure, the remaining processor will have the capability to assume the full workload, albeit at a reduced throughput rate. The two-computer configuration became operational in September 1975.

The second IBM 370/155 is an interim computer system, as was the initial system. The combined capacity of the two computers will experience saturation late in fiscal year 1976. Accordingly, the CCD plans to procure a larger computer system to replace the two IBM 370/155 computers.

TIME-SHARING SYSTEMS

To provide automatic data-processing support to its energy program and related activities, the USGS plans to procure three fully compatible time-sharing-oriented computers to be used in Denver, Colo.; Menlo Park, Calif.; and Reston, Va. All three computers will be accessed by numerous terminals. Sixteen large data bases will be maintained on the computers. Image-manipulation techniques using CRT graphic devices and minicomputers monitoring scientific instrumentation will be used in support of scientific computations.

DATA COMMUNICATIONS

Expanding requirements

Remote processing of data by an expanding data-communications network continued to increase during 1975. Approximately 70 terminals are connected to National Center computers for remote job-entry processing of batch-oriented tasks, an increase of over 30 percent from 1974. The greatest increase was realized in the technique of interactive processing, where keyboard and CRT terminals provide the facility for accessing data bases, retrieving information, executing computational algorithms, or creating computer programs in a conversational mode with computers. Nearly 140 interactive terminals are currently installed throughout the United States for use by USGS scientists.

Dedicated network

The planned acquisition of three compatible time-sharing computers for Menlo Park, Denver, and Res-

ton will generate a further increase in data-communications traffic within the USGS. A study is currently in progress to determine the parameters and cost of a dedicated USGS network to efficiently accommodate data-communications requirements from 1976 to 1980. Planning inputs forecast nearly 600 terminals in use by 1980, with a 100/500 split of remote job-entry versus interactive processing. The planned network will make use of the most current data-communications technology and will be modular in concept.

Problem diagnosis

The CCD has developed and incorporated into the data-communications control program a software routine that isolates communications problems. The routine determines whether the problem is associated with remote terminal hardware or with the communications line and thereby reduces the time required for problem solving. The routine also incorporates an automatic disconnect feature to prevent overloading of data-communication ports during periods of excessive line problems.

DATA-BASE MANAGEMENT SYSTEM

The USGS has procured System 2000, a general-purpose data-base management system. The basic system 2000 provides the user with a comprehensive set of data-base management capabilities, including the ability to define new data bases, modify the definition of existing data bases, and retrieve and update values in these data bases.

System 2000 was installed in the fall of 1974 and is currently being used for the Ground-Water Site Inventory System by the Water Resources Division. Other divisions within the USGS are planning and designing systems to be implemented by using the flexible power of System 2000.

NEW SOFTWARE SUPPORT

Significant enhancements were made to the control program of the IBM 370/155 in the fall of 1974. Analysis of performance-measurement information revealed that one routine of this program consumed an exorbitant amount of central processing unit (CPU) time. By modifying this routine, a better than threefold reduction in CPU time was realized, and an additional 4 h of available time was gained for user applications. This enhancement forestalled the saturation of the single IBM 370/155 by nearly a year.

NEW FACILITIES

Rolla, Missouri

A Systems Engineering Laboratories, Inc., model 86 computer system was installed in March 1975. This system replaced the IBM 360/20 computer terminal and provides more efficient and flexible support for the Midcontinent Mapping Center. The computer system can operate as a computer terminal to the Reston IBM 370/155 complex as well as concurrently provide local computational support. This increased support enables the implementation of new methods of analytical aerotriangulation and will encourage investigations into new computer applications for more efficient operations.

Sioux Falls, South Dakota

A contract has been awarded for the installation of a Burroughs Corporation B 6700 computer system at the EROS Data Center. Installation was accomplished in September 1975. The system will replace the existing IBM 360/30 and will continue the support needed to (1) catalog the data of the ERS program and ongoing aircraft photography programs; (2) answer requests and fill orders from the public; and (3) schedule the operation of the EROS Data Center. In addition, the system will support new applications in digital image processing and analysis.

U.S. GEOLOGICAL SURVEY PUBLICATIONS

PUBLICATIONS PROGRAM

Books and maps

Results of research and investigations by the USGS are made available to the public through professional papers, bulletins, water-supply papers, circulars, miscellaneous reports, and several map and atlas series, most of which are published by the USGS. Of these reports, books are printed by the Government Printing Office, and maps are printed by the USGS; both books and maps are sold by the USGS.

All books, maps other than topographic quadrangle maps, and related USGS publications are listed in the catalog "Publications of the Geological Survey, 1879–1961" and "Publications of the Geological Survey, 1962–1970" and in yearly supplements, available on request, that keep the catalogs up to date.

New publications, including topographic quadrangle maps, are announced monthly in "New Publications of the Geological Survey." A free subscription to this list may be obtained on application to the *U.S. Geological Survey, 329 National Center, Reston, VA 22092.*

State list of publications on hydrology and geology

"Geologic and Water-Supply Reports and Maps, [State]," a series of booklets, provides a ready reference to these publications on a State basis. The booklets also list libraries in the subject State where USGS reports and maps may be consulted; these booklets are available free on request to the USGS.

Surface-water and quality-of-water records

Beginning with the 1961 water year, surface-water records have been released on a State-boundary basis in separate annual reports entitled "Water Resources Data for [State]: Part 1, Surface Water Records." The records will also be published in the USGS series of water-supply papers at 5-yr intervals. The first group of "Surface Water Supply" papers covers the water years 1961–65.

Publication of quality-of-water records began in the annual State series in 1964 as "Water Resources Data for [State]: Part 2, Water Quality Records." The annual publication in the USGS water-supply papers of "Quality of Surface Water of the United States" by drainage basins has been continued. Distribution of the State water-resource data, Parts 1 and 2, is limited and primarily for local needs. These reports are free on request to Water Resources Division district offices (listed on p. 323) in areas for which records are needed.

Indexes, by drainage basins, of surface-water records to September 30, 1970, are published in the USGS series of circulars, issues of which are free on application to the *Branch of Distribution, U.S. Geological Survey, 1200 South Eads Street, Arlington, VA 22202.* These indexes list all streamflow and reservoir stations for which records have been published in USGS reports.

State water-resource investigations folders

A series of folders entitled "Water-Resources Investigations in [State]" is a project of the Water Resources Division to inform the public about its current program in the 50 States and Puerto Rico, the U.S. Virgin Islands, Guam, and American Samoa. As the programs change, the folders are revised. The folders are available free on request to the *U.S. Geological Survey, 435 National Center, Reston, VA 22092,* or to the Water Resources Division district offices listed on page 323.

Open-file reports

Open-file reports, which consist of manuscript reports, maps, and other preliminary material, are made available for public consultation and use. Arrangements can generally be made to reproduce them at private expense. The date of release and places of availability for consultation are given in news releases or other forms of public announcement. Since May 1974, all reports and maps released only in the open files have been listed monthly in "New Publications of the Geological Survey." For reports issued before this date, a listing has been published annually in the circular series. Most open-file reports are placed in one or more of the three USGS libraries:

950 National Center, Reston, Va.; Box 25046, Federal Center, Denver, Colo.; and 345 Middlefield Road, Menlo Park, Calif. Other depositories may include one or more of the USGS offices listed on page 318 and interested State agencies. Many open-file reports are superseded later by formally printed publications.

Journal of Research of the U.S. Geological Survey

The "Journal of Research of the U.S. Geological Survey" is a bimonthly periodical designed to provide relatively rapid publication of short scientific papers by USGS personnel. It replaces the short-papers chapters of the annual "Geological Survey Research" series of professional papers, issued from 1960 through 1972.

Earthquake Information Bulletin

The "Earthquake Information Bulletin" is published bimonthly by the USGS to provide information on earthquakes and seismological activities of interest to both general and specialized readers. It also lists pertinent publications and selected future professional meetings of Earth-science groups.

PUBLICATIONS ISSUED

During fiscal year 1975, the USGS published 4,956 maps comprising some 18,273,769 copies, as follows:

Kind of map printed	1975
Topographic	4,532
Geologic and hydrologic	366
Maps for inclusion in book reports	42
Miscellaneous (including maps for other agencies	16
Total	4,956

In addition, 6 issues of the "Journal of Research" comprising about 52,280 copies, 6 issues of the "Earthquake Information Bulletin" comprising about 30,000 copies, 169 technical book reports, and 2,575 leaflets and maps of flood-prone areas were published.

At the beginning of the fiscal year, more than 92.5 million copies of maps and book reports were on hand in the USGS's distribution centers. During the year, 10,564,075 copies of maps, including 551,575 index maps, were distributed. Approximately 7.8 million maps were sold, and $3,456,000 was deposited to Miscellaneous Receipts in the U.S. Treasury.

The USGS also distributed 384,925 copies of technical book reports, without charge and for official use, and 1,475,600 copies of booklets, free of charge, chiefly to the general public; 239,550 copies of the monthly publications announcements and 108,500 copies of a sheet showing topographic map symbols were sent out.

The total distribution resulted from receipt of 782,475 individual orders. The following table compares USGS map and book distribution (including booklets but excluding map-symbol sheets and monthly announcements) during fiscal years 1974 and 1975:

Number of maps and books distributed

Distribution points	Fiscal year 1974	Fiscal year 1975	Change (percent)
Eastern (Arlington, Va.)	6,010,586	6,499,087	+8
Central (Denver, Colo.)	4,598,479	4,938,330	+7
Alaska (Fairbanks)	123,317	129,949	+5
12 other USGS offices	794,435	857,234	+7
Total	11,526,817	12,424,600	+7

HOW TO OBTAIN PUBLICATIONS

OVER THE COUNTER

Book reports

Book reports (professional papers, bulletins, water-supply papers, "Topographic Instructions," "Techniques of Water-Resources Investigations," certain leaflets in bulk quantity, and some miscellaneous reports) can be purchased from the *Branch of Distribution, U.S. Geological Survey, 1200 South Eads Street, Arlington, VA 22202,* and from the USGS Public Inquiries Offices listed on page 322 (authorized agents of the Superintendent of Documents).

Some book publications that can no longer be obtained from the Superintendent of Documents are available for purchase from the above authorized agents of the Superintendent of Documents.

Maps and charts

Maps and charts may be purchased at the following USGS offices:

1200 South Eads St., Arlington, Va.
900 Pine St., Rolla, Mo.
Box 25286, Federal Center, Denver, Colo.
345 Middlefield Rd., Menlo Park, Calif.
Room 441, Federal Bldg., 709 West Ninth St., Juneau, Alaska
310 First Ave., Fairbanks, Alaska
Public Inquiries Offices listed on page 322

USGS maps are also sold by some 1,500 commercial dealers throughout the United States. Prices charged are generally higher than those charged by USGS offices.

Indexes showing topographic maps published for each State, Puerto Rico, the U.S. Virgin Islands,

Guam, American Samoa, and Antarctica are available free on request. Publication of revised indexes to topographic mapping is announced in the monthly "New Publications of the Geological Survey." Each index also lists special and U.S. maps, as well as USGS offices and commercial dealers from which maps may be purchased.

Maps, charts, folios, and atlases that are out of print can no longer be obtained from any official source. These may be consulted at many libraries, and some can be purchased from secondhand-book dealers.

BY MAIL

Book reports

Technical book reports, certain leaflets in bulk quantity, and some miscellaneous reports can be ordered from the *Branch of Distribution, U.S. Geological Survey, 1200 South Eads Street, Arlington, VA 22202*. Prepayment is required and should be made by check or money order payable to the U.S. Geological Survey. Postage stamps are not accepted; please do not send cash. On orders of 100 copies or more of the same report to the same address, a 25-percent discount is allowed. Circulars and some miscellaneous reports may be obtained free from this Branch.

Maps and charts

Maps and charts, including folios and hydrologic atlases, are sold by the USGS. Address orders to *Branch of Distribution, U.S. Geological Survey, 1200 South Eads Street, Arlington, VA 22202*, for maps of areas east of the Mississippi River, including Minnesota, Puerto Rico and the U.S. Virgin Islands, and to *Branch of Distribution, U.S. Geological Survey, P.O. Box 25286, Federal Center, Denver, CO 80225*, for maps of areas west of the Mississippi, including Alaska, Hawaii, Louisiana, Guam, and American Samoa. Residents of Alaska may also order maps of their State from the *Alaska Distribution Section, U.S. Geological Survey, 310 First Avenue, Fairbanks, AK 99701*.

Prepayment is required. Remittances should be by check or money order payable to the U.S. Geological Survey. On an order amounting to $300 or more at the list price, a 30-percent discount is allowed. Prices are quoted in lists of publications and in indexes to topographic mapping for individual States. Prices include the cost of surface transportation.

Journal of Research of the U.S. Geological Survey and Earthquake Information Bulletin

Subscriptions to the "Journal of Research of the U.S. Geological Survey" and the "Earthquake Information Bulletin" are by application to the *Superintendent of Documents, Government Printing Office, Washington, DC 20402*. Payment is by check payable to the Superintendent of Documents or by charge to your deposit account number. Single issues may also be purchased from the Superintendent of Documents.

Advance material from mapping

Advance material available from current topographic mapping is indicated on individual State index maps, which are 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. Ordering information 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 *National Cartographic Information Center, U.S. Geological Survey, 507 National Center, Reston, VA 22092*.

EROS Data Center materials

USGS aerial photography, NASA aircraft photography and imagery, LANDSAT (formerly called ERTS) imagery, and Skylab imagery and photography are sold by the USGS, as are copies of the photography and imagery produced on 16-mm browse film, which are designed for prepurchase evaluation. LANDSAT Standard Catalogs are also sold. Address requests for price list, additional information, and orders to *EROS Data Center, U.S. Geological Survey, Sioux Falls, SD 57198*. Prepayment is required for orders. Remittances should be made payable to the U.S. Geological Survey.

National Technical Information Service

Some USGS reports, including computer programs, data and information supplemental to map or book publications, and data files, are released through the National Technical Information Service (NTIS). These reports, available either in paper copies or in microfiche or sometimes on magnetic tapes, can be purchased only from *National Technical Information Service, U.S. Department of Commerce, Springfield, VA 22161*. USGS reports that are released through NTIS, together with their NTIS order numbers and prices, are announced in the monthly "New Publications of the Geological Survey."

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COOPERATORS AND OTHER FINANCIAL CONTRIBUTORS DURING FISCAL YEAR 1975

[Cooperators listed are those with whom the U.S. Geological Survey had a written agreement for fiscal cooperation in fiscal year 1975, cosigned by responsible officials of the Geological Survey and 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

Department of Agriculture:
- Agriculture Research Service
- Forest Service
- Soil Conservation Service
- Statistical Reporting Service

Department of the Air Force:
- AFWL/PRP Kirtland AFB
- Air Force Academy
- Air Force Headquarters, Washington, D.C.
- Air Force Systems Command
- Air Force Weapons Laboratory (PRP)
- Alaskan Air Command
- Edwards Air Force Base
- Eglin Air Force Base
- Headquarters (AF-SC)
- Headquarters (AFTAC/AC)
- Headquarters Pacific Air Forces
- Headquarters 321st Combat Support Group (SAC)
- Homestead Air Force Base
- Office of Scientific Research
- Rocket Propulsion Laboratory
- Vandenburg Air Force Base

Department of the Army:
- Army Electronics Command
- Army Research Office
- Cold Regions Research and Engineering Laboratory
- Construction Engineering Research Laboratory
- Corps of Engineers
- White Sands Missile Range

Department of Commerce, National Oceanic and Atmospheric Administration:
- Buoy Office
- Environmental Data Service
- Environmental Research Laboratories
- National Environmental Satellite Service
- National Marine Fisheries Service
- National Ocean Survey
- National Weather Service

Department of Defense:
- Advanced Research Projects Agency
- Defense Intelligence Agency

Department of Defense—Continued
- Defense Mapping Agency (IAGS)
- Defense Nuclear Agency
- U.S. Arms Control and Disarmament Agency

Department of Health, Education, and Welfare, Public Health Service

Department of Housing and Urban Development

Department of the Interior:
- Alaska Power Administration
- Bonneville Power Administration
- Bureau of Indian Affairs
- Bureau of Land Management
- Bureau of Mines
- Bureau of Outdoor Recreation
- Bureau of Reclamation
- Fish and Wildlife Service
- National Park Service
- Forest Service
- Office of Land Use and Water Planning
- Office of Saline Water
- Office of Water Resources Research
- U.N. Geothermal Symposium
- Water Resources Council

Department of Justice

Department of the Navy:
- Key West Naval Station
- Marine Corps, Camp Pendleton
- Naval Air Development Center
- Naval Facilities Engineering Command
- Naval Weapons Center
- Office of Naval Petroleum and Oil Shale Reserves
- Office of Naval Research
- Public Works Center, Guam

Department of State:
- Agency for International Development
- International Boundary and Water Commission
- International Joint Commission

Department of Transportation:
- Federal Highway Administration
- Office of the Secretary

Energy Research and Development Administration:
- Albuquerque Operations Office
- Division of Applied Technology
- Division of Administrative Services
- Division of Reactor Research and Development
- Idaho Operations Office
- Nevada Operations Office
- Oak Ridge Operations Office
- Office of the Director of Regulation
- Richland Operations Office
- Rocky Flats Division
- San Francisco Operations Office
- Savannah River Operations Office

Environmental Protection Agency:
- Management Division
- National Environmental Research Center
- Office of Radiation Programs
- Office of Research and Development
- Office of Solid Waste
- Office of Water Programs
- Pacific Northwest Environmental Research Laboratory
- Water and Hazardous Materials

Federal Energy Administration

General Services Administration

National Academy of Sciences

National Aeronautics and Space Administration

National Science Foundation

Nuclear Regulatory Commission

Office of Emergency Preparedness

Pacific Northwest River Basins Commission

Tennessee Valley Authority

Veterans Administration

STATE, COUNTY, AND LOCAL COOPERATORS

Alabama:
- Alabama Forestry Commission
- Alabama Highway Department
- City of Mobile
- County of Jefferson
- Geological Survey of Alabama

Alaska:
- Alaska Department of Aviation
- Alaska Department of Fish and Game
- Alaska Department of Highways
- Alaska Department of Natural Resources
- Alaska Geological Survey

Alaska—Continued
- City and Borough of Juneau
- City of Anchorage
- City of Cordova
- City of Kenai
- City of Kodiak
- City of Seward
- Department of Environmental Conservation
- Greater Anchorage Area Borough
- Kenai Borough
- North Star Borough
- University of Alaska

Arizona:
- Arizona Game and Fish Department
- Arizona Highway Department
- Arizona Water Commission
- City of Flagstaff
- City of Nogales
- City of Safford
- City of Tucson
- City of Williams
- Department of Health Services
- Flood Control District of Maricopa County
- Gila Valley Irrigation District
- Lyman Water Company
- Maricopa County Municipal Water Conservation District No. 1
- Office of the Governor
- Pima County Board of Supervisors
- Salt River Valley Water User's Association
- San Carlos Irrigation and Drainage District
- Show Low Irrigation Company
- University of Arizona

Arkansas:
- Arkansas Department of Pollution Control and Ecology
- Arkansas Division of Soil and Water Resources
- Arkansas Geological Commission
- Arkansas State Highway Commission

California:
- Alameda County Flood Control and Water Conservation District
- Alameda County Water District
- Antelope Valley-East Kern Water Agency
- Berrenda Mesa Water District
- Big Bear Lake Pest Abatement District
- California Department of Conservation, Division of Mines and Geology
- California Department of Fish and Game
- California Department of Water Resources
- California Division of Highways, Materials and Research Department
- California Water Resources Control Board
- Casitas Municipal Water District
- Chino Basin Municipal Water District
- City and County of San Francisco:
  - Hetch Hetchy Water Supply
  - Water Department

California—Continued
- City of Modesto, Public Works Department
- City of Redding
- City of San Diego
- City of San Jose
- City of San Rafael
- City of Santa Barbara
- City of Santa Cruz
- Coachella Valley County Water District
- Contra Costa County Flood Control and Water Conservation District
- County of Fresno
- County of Madera
- County of Modoc
- County of Sacramento, Department of Public Works
- County of San Diego, Board of Supervisors
- County of San Mateo
- Department of Transportation, Office of Structures
- Desert Water Agency
- East Bay Municipal Utility District
- Fern Valley Water District
- Georgetown Divide Public Utility District
- Goleta County Water District
- Hoopa Valley Tribe
- Imperial County Department of Public Works
- Imperial Irrigation District
- Indian Wells Valley County Water District
- Kern County
- Kern County Water Agency
- Lake County Flood Control and Water Conservation District
- Livermore Amador Valley Water Management Agency
- Los Angeles County, Department of County Engineers
- Los Angeles County Flood Control District
- Los Angeles Department of Water and Power
- Madera Irrigation District
- Marin Municipal Water District
- Merced Irrigation District
- Metropolitan Water District of Southern California
- Mojave Water Agency
- Montecito County Water District
- Monterey County Flood Control and Water Conservation District
- Napa County Flood Control and Water Conservation District
- North Marin County Water District
- Orange County Flood Control District
- Orange County Water District
- Oroville-Wyandotte Irrigation District
- Pacheco Pass Water District
- Paradise Irrigation District
- Placer County Department of Public Works
- 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 Luis Obispo County and Cities Area Planning Coordinating Council

California—Continued
- San Luis Obispo County Flood Control and Water Conservation District
- Santa Ana Watershed Planning Agency
- Santa Barbara County Flood Control and Water Conservation District
- Santa Barbara County Water Agency
- Santa Clara County Flood Control and Water District
- Santa Cruz County Flood Control and Water Conservation District
- Santa Cruz County Planning Department
- Santa Margarita and San Luis Rey Watershed Planning Agencies
- Santa Maria Valley Water Conservation District
- Santa Ynez River Water Conservation District
- Siskiyou County Flood Control and Water Conservation District
- Solano Irrigation District
- Tehachapi-Cummings County Water District
- Terra Bella Irrigation District
- Tulare County Flood Control District
- Turlock Irrigation District
- United Water Conservation District
- University of California:
  - Department of Engineering
  - School of Forestry and Conservation
  - Scripps Institute of Oceanography
- Valley Community Services District
- Valley Sanitary District
- Ventura County Flood Control District, Riverside County
- Western Municipal Water District
- Woodbridge Irrigation District
- Yolo County Flood Control and Water Conservation District

Colorado:
- Arkansas River Compact Administration
- Cherokee Water District
- City and County of Denver, Board of Water Commissioners
- City of Aspen
- City of Aurora, Department of Public Utilities
- City of Colorado Springs, Department of Public Utilities
- City of Fort Collins
- City of Pueblo
- Colorado City Water and Sanitation District
- Colorado Department of Local Affairs
- Colorado Department of Natural Resources:
  - Division of Water Resources
  - Division of Wildlife
  - Geological Survey
- Colorado Department of Public Health, Water Pollution Control Commission
- Colorado River Water Conservation District
- Colorado Water Conservation Board
- Eagle County Commissioners
- El Paso County Board of Commissioners
- El Paso County Water Association
- Huerfano County Conservation District
- Jefferson County Health Department
- Kiowa-Bijou Groundwater Management District

Colorado—Continued
- Larimer County Planning Office
- Lower South Platte Water Conservation District
- Metro Denver Sewage Disposal District No. 1
- Northern Colorado Water Conservation District
- Pikes Peak Area Council of Governments
- Pitkin County Board of County Commissioners
- Rio Grande Water Conservation District
- San Luis Valley Water Conservation District
- Southeastern Colorado Water Conservancy District
- Southern Ute Indian Tribe
- Southwestern Water Conservation District
- State of Colorado, Department of Highways
- Teller County
- Urban Drainage and Flood Control District

Connecticut:
- City of Hartford, Department of Public Works
- City of New Britain, Board of Water Commissioners
- City of Torrington
- Connecticut Geological and Natural History Survey
- Department of Environmental Protection
- Department of Transportation
- State of Connecticut, Office of State Planning
- Town of Fairfield

Delaware:
- Delaware Geological Survey, University of Delaware
- Department of Highways and Transporation, Division of Highways

District of Columbia:
- Department of Environmental Services

Florida:
- Brevard County
- Broward County
- Broward County Air and Water Pollution Control Board
- Central and Southern Florida Flood Control District
- City of Boca Raton
- City of Clearwater
- City of Cocoa
- City of Deerfield Beach
- City of Fort Lauderdale
- City of Fort Myers
- City of Gainesville
- City of Hallandale
- City of Hollywood
- City of Jacksonville
- City of Juno Beach
- City of Miami, Department of Water and Sewers
- City of Pensacola
- City of Perry
- City of Pompano Beach
- City of Riviera Beach
- City of St. Petersburg
- City of Sarasota
- City of Tallahassee
- City of Tampa
- City of Temple Terrace

Florida—Continued
- City of West Palm Beach
- Collier County
- Collier County Water Management District No. 1
- Collier County Water Management District No. 7
- Department of Pollution Control
- Division of State Planning
- East Central Florida Regional Planning Council
- Englewood Water District
- Escambia County
- Florida Department of Natural Resources:
  - Bureau of Geology
  - Division of Parks and Recreation
- Florida Department of Transportation
- Game and Fresh Water Fish Commission
- Hendry County
- Hillsborough County
- Jacksonville Area Planning Board
- Jacksonville Recreation and Public Area
- Lake County
- Lake Worth Drainage District
- Lee County
- Loxahatchee River Environmental Control District
- Manasota Basin Board
- Manatee County, Board of County Commissioners
- Marion County
- Martin County
- Metropolitan Dade County
- Northwest Florida Water Management District
- Orange County
- Osceola County
- Palm Beach County
- Pinellas County
- Reedy Creek Improvement District
- Sarasota County
- School of Marine and Atmospheric Science, University of Miami Division of Planning
- Seminole County
- Southwest Water Management District
- St. Johns River Water Management
- Suwanee River Authority
- Suwanee River Water Management District
- Tampa Bay Regional Planning Commission
- Tampa Port Authority
- Village of Tequesta
- Volusia County
- Walton County

Georgia:
- Chatham County
- City of Brunswick
- Dekalb County
- Department of Natural Resources:
  - Earth and Water Division
  - Environmental Protection Division
- Department of Transportation

Hawaii:
- City and County of Honolulu
- Honolulu Board of Water Supply

Hawaii—Continued
- State Department of Health
- State Department of Land and Natural Resources
- State Department of Transportation

Idaho:
- City of Kellogg
- Idaho Bureau of Mines and Geology
- Idaho Department of Health and Welfare
- Idaho Department of Highways
- Idaho Department of Transportation
- Idaho Department of Water Administration
- Idaho State University
- Idaho Water Resources Board
- Southeast Idaho Council of Governments

Illinois:
- Bloomington and Normal Sanitary District
- City of Springfield
- Cook County, Forest Preserve District
- Du Page County
- Environmental Protection Agency
- Fountain Head Drainage District
- Fulton County
- Illinois Institute of Environmental Quality
- Kane County
- Lake County
- McHenry County Regional Planning Commission
- Sanitary District of Bloom Township
- State Department of Registration and Education:
  - Illinois State Geological Survey
  - Illinois State Water Survey
- State Department of Transportation:
  - Division of Highways
  - Division of Water Resources Management
- The Metropolitan Sanitary District of Greater Chicago
- University of Illinois at Urbana-Champaign

Indiana:
- City of Indianapolis
- Indiana Board of Health
- Indiana Department of Natural Resources
- Indiana Highway Commission
- Town of Carmel

Iowa:
- City of Cedar Rapids
- City of Des Moines
- City of Fort Dodge
- Iowa Geological Survey
- Iowa Natural Resources Council
- Iowa State Highway Commission, Highway Research Board
- Iowa State University
- Iowa State University, Agricultural and Home Economics Experiment Station
- Linn County
- University of Iowa, Institute of Hydraulic Research

Kansas:
- City of Wichita
- Kansas State Department of Health

Kansas—Continued
- Kansas State Water Resources Board
- Kansas-Oklahoma Arkansas River Commission
- State Geological Survey of Kansas
- State Highway Commission of Kansas

Kentucky:
- Bureau of Highways, Department of Transportation
- Department of Natural Resources
- Kentucky Geological Survey, University of Kentucky
- University of Kentucky Research Foundation

Louisiana:
- Louisiana Department of Highways
- Louisiana Department of Public Works
- Louisiana Office of State Planning
- Louisiana State University
- Sabine River Authority of Louisiana
- Sabine River Compact Administration

Maine:
- Department of Environmental Protection
- Maine Department of Economic Development
- Maine Department of Transportation
- Maine Geological Survey
- Maine Public Utilities Commission

Maryland:
- City of Baltimore, Water Division
- Department of Natural Resources, Water Resources Administration
- Maryland Department of Health and Mental Hygiene
- Maryland Department of Transportation, The State Highway Administration
- Maryland Geological Survey
- Maryland National Capital Park and Planning Commission
- Montgomery County
- Washington Suburban Sanitary Commission

Massachusetts:
- Department of Natural Resources, Division of Mineral Resources
- Department of Public Works:
  - Division of Highways
  - Division of Waterways
- Metropolitan District Commission
- State Water Resources Commission:
  - Division of Water Pollution Control
  - Division of Water Resources

Michigan:
- Michigan Department of Agriculture, Soil and Water Conservation Division
- Michigan Department of Natural Resources:
  - Geological Survey Division
  - Water Resources Commission

Minnesota:
- Metropolitan Council of the Twin Cities Area
- Metropolitan Sewer Board of the Twin Cities Area
- Minnesota Department of Highways

Minnesota—Continued
- Minnesota Department of Natural Resources, Division of Waters, Soils, and Minerals
- Minnesota Pollution Control Agency
- Minnesota State Planning Agency
- Pelican River Watershed District

Mississippi:
- City of Jackson
- 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
- Pat Harrison Waterway District
- Pearl River Basin Development District
- Pearl River Valley Water Supply District
- Yellow Creek Port Authority

Missouri:
- Curators of the University of Missouri
- Department of Natural Resources:
  - Division of Environmental Quality, Clean Water Commission
  - Research Technical Information
- Metropolitan St. Louis Sewer District
- Missouri Department of Business and Administration, Division of Geological Survey and Water Resources
- Missouri State Highway Commission
- Missouri Water Pollution Board
- St. Louis County

Montana:
- Endowment and Research Foundation—Montana State University
- Lewis and Clark County, Board of County Commissioners
- Montana Bureau of Mines and Geology
- Montana Department of Health and Environmental Sciences
- Montana Department of Intergovernmental Relations
- Montana Department of Natural Resources
- Montana State Fish and Game Department
- Montana State Highway Commission
- Old West Regional Commission

Nebraska:
- Clay County Ground Water Conservation District
- Filmore County Ground Water Conservation District
- Hamilton County Ground Water Conservation District
- Kansas-Nebraska Big Blue River Compact Administration
- Lower Loup Natural Resources District
- Lower Platte South Natural Resources District
- Nebraska Department of Environmental Control
- Nebraska Department of Water Resources
- Nebraska Game and Parks Commission
- Nebraska Natural Resources Commission
- Seward County Ground Water Conservation District
- State Department of Roads

Nebraska—Continued
- University of Nebraska, Conservation and Survey Division
- Upper Big Blue Natural Resources District
- York County Ground Water Conservation District

Nevada:
- Nevada Bureau of Mines and Geology
- 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 Hampshire Water Supply and Pollution Control Commission

New Jersey:
- Bergen County
- Camden County Board of Freeholders
- Delaware River Basin Commission
- New Jersey Department of Agriculture, State Soil Conservation Committee
- New Jersey Department of Environmental Protection
- New Jersey Department of Transportation
- North Jersey District Water Supply Commission
- Passaic Valley Water Commission
- Rutgers State University
- Township of Cranford

New Mexico:
- Albuquerque Metropolitan Arroyo Flood Control Authority
- City of Las Cruces
- Costilla Creek Compact Commission
- Elephant Butte Irrigation District
- Interstate Stream Commission
- New Mexico Bureau of Mines and Mineral Resources
- New Mexico State Engineer
- New Mexico State Highway Department
- Pecos River Commission
- Rio Grande Compact Commission
- University of New Mexico

New York:
- Board of Hudson River—Black River Regulating District
- Central New York State Parks Commission
- City of Albany
- City of Auburn
- City of New York:
  - Board of Water Supply
  - Environmental Protection Agency
- County of Chautauqua
- County of Cortland
- County of Dutchess:
  - Board of Supervisors
  - Department of Public Works
- County of Nassau, Department of Public Works
- County of Onondaga:
  - Department of Public Works
  - Water Authority
- County of Orange

New York—Continued
- County of Putnam
- County of Rockland Drainage Agency
- County of Suffolk:
  - Department of Environmental Control
  - Water Authority
- County of Ulster, Ulster County Legislature
- County of Westchester, Department of Public Works
- County of Wyoming
- Department of Environmental Conservation:
  - Environmental Management
  - Environmental Quality
  - Environmental Research
  - Facilities and Construction Management
- Department of Transportation
- Monroe County Water Authority
- New York State College of Agriculture and Life Sciences
- New York State Department of Health
- New York State Education Department, Museum and Science Service
- Oswegatchie-Cranberry Reservoir Commission
- Power Authority of the State of New York
- State University of New York, College of Environmental Science and Forestry
- Town of Brighton
- Town of Clarkstown
- Town of Middlebury
- Town of Warwick
- 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 Winston-Salem
- North Carolina Department of Conservation and Development, Division of Mineral Resources
- North Carolina Department of Natural and Economic Resources, Office of Earth Resources
- North Carolina Department of Water and Air Resources
- State Department of Transportation
- Triangle "J" Council of Governments
- Water Research Institute
- Wilson County

North Dakota:
- North Dakota Geological Survey
- Oliver County, Board of County Commissioners
- State Highway Department
- State Water Commission

Ohio:
- City of Canton
- City of Columbus, Department of Public Service
- Miami Conservancy District
- Ohio Department of Natural Resources
- Ohio Department of Transportation
- Ohio Department of Transportation, Division of Highways
- Ohio Environmental Protection Agency

Ohio—Continued
- Three Rivers Watershed District

Oklahoma:
- City of Oklahoma City, Water Department
- Oklahoma Department of Highways
- Oklahoma Geological Survey
- Oklahoma Soil Conservation Board
- Oklahoma Water Resources Board
- State Department of Health, Environmental Health Service

Oregon:
- Burnt River Irrigation District
- City of Astoria
- City of Corvallis
- 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
- Confederated Tribes of the Umatilla Indian Reservation
- Confederated Tribes of the Warm Springs Reservation
- Coos Bay-North Bend Water Board
- Coos County, Board of Commissioners
- Cowlitz County
- Douglas County
- Lakeside Water District
- Lane County, Department of General Administration
- Oregon State Board of Higher Education
- Oregon State Game Commission
- Oregon State Highway Commission
- Oregon State Water Resources Department

Pennsylvania:
- Chester County Commissioners
- Chester County Health Department
- Chester County Water Resources Authority
- City of Bethlehem
- City of Easton
- City of Harrisburg
- City of Philadelphia, Water Department
- Department of Environmental Management
- Pennsylvania Department of Environmental Resources:
  - Bureau of Topographic and Geologic Survey
  - Bureau of Water Quality Management
  - Office of Engineering and Construction
  - State Soil and Water Conservation Commission
- Pennsylvania Department of Transportation
- Pennsylvania Office of State Planning and Development
- Susquehanna River Basin Commission

Rhode Island:
- City of Providence, Department of Public Works
- State Department of Natural Resources:
  - Division of Fish and Wildlife
  - Division of Planning and Development
- State Department of Transportation, Division of Roads and Bridges
- State Water Resources Board

South Carolina:
- Commissioners of Public Works, Spartanburg Water Works

South Carolina—Continued
- South Carolina State Development Board
- State Development Board, Division of Geology
- State Highway Department
- State Land Resources Conservation Commission
- State Pollution Control Authority
- State Public Service Authority
- State Water Resources Commission

South Dakota:
- Black Hills Conservancy Subdistrict
- City of Sioux Falls
- City of Watertown
- East Dakota Conservancy Subdistrict
- South Dakota Department of Natural Resource Development
- South Dakota Department of Transportation and State Geological Survey

Tennessee:
- Chickasaw Basin Authority
- City of Chattanooga
- City of Franklin
- City of Lawrenceburg
- City of Manchester
- City of Memphis, Board of Light, Gas, and Water Commissioners
- Lincoln County
- 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, Division of Water Quality Control
- Tennessee Department of Transportation
- Tennessee Game and Fish Commission
- Tennessee State Planning Office
- University of Tennessee

Texas:
- City of Austin
- City of Dallas, Public Works Department
- City of Fort Worth
- City of Houston
- County of Dallas
- Sabine River Compact Administration
- Texas Highway Department
- Texas Water Development Board

Utah:
- Bear River Commission
- Salt Lake County
- State Department of Highways
- State Department of Natural Resources, Division of Water Rights
- Utah Geological and Mineralogical Survey
- Utah Legislative Council

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
- Virginia Polytechnic Institute and State University
- Virginia State Water Control Board

Washington:
- Chehalis Tribal Council
- 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
- Coleville Business Council
- Cowlitz County Public Utility District
- Municipality of Metropolitan Seattle
- Pacific County
- Quinault Business Committee
- Squaxin Indian Tribe
- Swinomish Tribal Council
- The Evergreen State College
- Tulalip Tribal Council
- University of Washington
- Washington State Department of Ecology
- Washington State Department of Fisheries
- Washington State Department of Game
- Washington State Department of Highways
- Washington State Department of Natural Resources, Division of Mines and Geology
- Yakima Tribal Council

West Virginia:
- Clarksburg Water Board
- Morgantown Water Commission
- West Virginia Department of Highways
- West Virginia Department of Natural Resources, Division of Water Resources
- West Virginia Geological and Economic Survey

Wisconsin:
- City of Madison
- City of Middleton
- Dane County

Wisconsin—Continued
- Douglas County
- Madison Metropolitan Sewerage District
- Southeastern Wisconsin Regional Planning Commission
- State Department of Natural Resources
- State Department of Transportation, Division of Highways
- The University of Wisconsin-Extension, Geological and Natural History Survey
- Town of Kronenwetter

Wyoming:
- 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 State Agriculture Commission
- Wyoming State Department of Environmental Quality
- Wyoming State Engineer

OTHER COOPERATORS AND CONTRIBUTORS

Appalachian Regional Commission

Coastal Plains Regional Commission

Government of Algeria

Government of American Samoa

Government of Brazil

Government of Burma

Government of Colombia

Government of Guam

Government of Iran

Government of Jordan

Government of Nepal

Government of Nicaragua

Government of Oman

Government of Peru

Government of the Philippines

Government of Saudi Arabia

Government of Thailand

Government of Turkey

Government of Yemen

Northern Great Plains Resources Programs

Ozarks Regional Commission

Permittees and licensees of the Federal Power Commission

Puerto Rico:
- Gobierno Municipal De Bayamón
- Puerto Rico Department of Natural Resources
- Puerto Rico Environmental Quality Board
- Puerto Rico Water Resources Authority

Trust Territory of the Pacific Islands

United Nations

Virgin Islands, Department of Public Works

U.S. GEOLOGICAL SURVEY OFFICES

HEADQUARTERS OFFICES

Official and (or) office	*Name and telephone number*	*Address*
Director	V. E. McKelvey (703 860-7411)	101 National Center.
Associate Director	W. A. Radlinski (703 860-7411)	102 National Center.
Senior Scientist	Frank E. Clarke (202 343-3888)	Rm. 4441, Interior Bldg., Washington, D.C. 20240.
Assistant Director, Research	James R. Balsley (703 860-7488)	104 National Center.
Assistant Director, Programs	Dale D. Bajema (acting) (703 860-7435).	105 National Center.
Assistant Director, Environmental Conservation.	Henry W. Coulter (703 860-7491)	106 National Center.
Assistant Director, Administration	Edmund J. Grant (703 860-7201)	201 National Center.
Assistant Director	Montis R. Klepper (703 860-7481)	171 National Center.
Chief, Office of Land Information and Analysis.	James R. Balsley (acting) (703 860-7488).	104 National Center.
Earth Resources Observation Systems Program.	John M. DeNoyer (703 860-7881)	1925 Newton Sq. East, Reston, Va., 22090.
Earth Sciences Applications Program.	Donald R. Nichols (703 860-7547)	104 National Center.
Environmental Impact Analysis	Daniel B. Krinsley (703 860-7455)	760 National Center.
Geography Program	James R. Anderson (703 860-6344)	115 National Center.
Resources and Land Information Program.	J. Ronald Jones (703 860-7435)	105 National Center.
Chief, Administrative Division	Edmund J. Grant (703 860-7201)	201 National Center.
Chief, Computer Center Division	Carl E. Diesen (703 860-7106)	801 National Center.
Chief, Conservation Division	Russell G. Wayland (703 860-7524)	600 National Center.
Chief, Geologic Division	Richard P. Sheldon (703 860-6531)	911 National Center.
Chief, Publications Division	Harry D. Wilson, Jr. (703 860-7181)	341 National Center.
Chief, Topographic Division	Robert H. Lyddan (703 860-6231)	516 National Center.
Chief, Water Resources Division	Joseph S. Cragwall, Jr. (703 860-6921).	409 National Center.

PRINCIPAL FIELD OFFICES

Official and (or) office	*Name and telephone number*	*Address*
Assistant Director, Eastern Region	William B. Overstreet (703 860-7414).	109 National Center.
Assistant Director, Central Region	Thad G. McLaughlin (303 234-4630).	Bldg. 25, Federal Center, Denver, Colo. 80225.
Assistant Director, Western Region	Joel M. Johanson (415 323-2711)	345 Middlefield Rd., Menlo Park, Calif. 94025.

SELECTED FIELD OFFICES IN THE UNITED STATES AND PUERTO RICO

[Temporary offices are not included; list is current as of July 1, 1975. Correspondence to the following offices should be addressed to the Post Office Box, if one is given]

COMPUTER CENTER DIVISION

Location	*Official in charge and telephone number*	*Address*
Arizona, Flagstaff 86001	James E. Crawforth (602 774-1312)	601 East Cedar Ave.
California, Menlo Park 94025	James L. Mueller (415 323-2661)	345 Middlefield Rd.
Colorado, Denver 80225	Frederick B. Sower (303 234-5277)	Rm. E2608, Bldg. 53, Federal Center.
Missouri, Rolla 65401	Glenn A. Ridgeway (314 364-6985)	P.O. Box 41.
South Dakota, Sioux Falls 57198	Ralph J. Thompson (605 594-6555)	EROS Data Center.

CONSERVATION DIVISION

REGIONAL OFFICES

Location	*Official in charge and telephone number*	*Address*
Central Region: Denver, CO 80225	George H. Horn, Regional Conservation Manager (303 234-2855).	Bldg. 25, Federal Center; Villa Italia, Wadsworth and Alameda.
Eastern Region: Washington, DC 20006	George F. Brown, Regional Conservation Manager (202 343-4685).	Suite 316, 1825 K St., NW.
Gulf of Mexico Outer Continental Shelf Operations: Metairie, LA 70011	A. Dewey Acuff, Conservation Manager (504 680-9381).	P.O. Box 7944; 336 Imperial Office Bldg., 3301 North Causeway Blvd.
Western Region: Menlo Park, CA 94025	Willard C. Gere, Regional Conservation Manager (415 323-2108).	345 Middlefield Rd.; 701 Laurel St.

AREA AND DISTRICT OFFICES

Location	*Official in charge and telephone number*	*Address*
Alaska, Anchorage 99510	Rodney A. Smith, Alexander A. Wanek (907 278-3571).	P.O. Box 259; 212 Skyline Bldg., 218 E St.
Arizona, Phoenix 85003	Vacant (602 261-3766)	Rm. 208, 522 North Central Ave.
California, Los Angeles 90012	Fred J. Schambeck, Keith A. Yenne (213 688-2846).	Rm. 7744, Federal Bldg., 300 North Los Angeles St.
Bakersfield 93301	Donald F. Russell (805 861-4186)	Rm. 309, Federal Bldg., 800 Truxtun Ave.
Menlo Park 94025	Leo H. Saarela (415 323-2108). Henry L. Cullins, Jr. (415 323-2563). Reid T. Stone (415 323-2841).	345 Middlefield Rd.; 701 Laurel St.
Sacramento 95825	Robert D. Morgan, (acting) (916 484-4219).	Rm. W-2231, Federal Bldg., 2800 Cottage Way.
Santa Barbara 93102	Michael F. Reitz (805 963-3305)	Rm. 214, Post Office Bldg., 836 Anacapa St.

Location	*Official in charge and telephone number*	*Address*
Colorado, Denver 80225	James A. Carter, (acting) (303 234-3984, 4484). John P. Storrs (303 837-4751). Sterling R. Osborne (303 234-5042). Daniel A. Jobin (303 234-4435).	Bldg. 25, Federal Center.
Durango 81301	Jerry W. Long (303 247-5144)	P.O. Box 1809; 125 West 10th St.
Grand Junction 81501	Peter A. Rutledge, James W. Hager (303 242-3281).	P.O. Box 2939; Federal Bldg., 4th St. and Rood Ave.
Idaho, Pocatello 83201	John T. Skinner (208 235-6262)	P.O. Box 1610; Federal Bldg., 150 South Arthur St.
Louisiana, Houma 70360	John Borne (504 868-4033)	P.O. Box 1269.
Lafayette 70501	Elmo G. Hubble, (318 232-6037)	P.O. Box 52289; 239 Bendel Rd.
Lake Charles 70601	Robert Darrow (318 478-6440)	P.O. Box 6088, Drew Station.
Metairie 70011	Harry McAndrews (504 680-9341). Donald W. Solanas (504 680-9333). Jake B. Lowenhaupt (504 680-9251). Charles B. Mullins (504 680-9301).	P.O. Box 7944; 336 Imperial Office Bldg., 3301 North Causeway Blvd. P.O. Box 7966.
Mississippi, Jackson 39201	Thomas E. Godfrey (601 969-4405)	505 Unifirst Federal Savings & Loan Bldg.
Missouri, Rolla 65401	C. V. Collins (314 364-8411)	P.O. Box 936; Suite 101, 400 Main St.
Montana, Billings 59103	Albert F. Czarnowsky (406 245-6181). Jim S. Hinds (406 245-6185). Virgil L. Pauli (406 245-6368).	P.O. Box 2550; 217 Post Office Bldg.
New Mexico, Artesia 88210	James A. Knauff (505 746-4841)	Drawer U; 105 South 4th St.
Carlsbad 88220	Robert S. Fulton (505 885-6454)	P.O. Box 1716; Federal Bldg., 114 South Halagueno St.
Farmington 87401	J. E. Fassett, Philip T. McGrath (505 325-4572).	P.O. Box 959; Petroleum Club Plaza, 3535 East 30th St.
Hobbs 88240	Arthur R. Brown (505 393-3612)	P.O. Box 1157; 205 North Linam St.
Roswell 88201	N. O. Frederick, Donald M. VanSickle (505 622-9257).	Drawer 1857; Federal Bldg. and U.S. Courthouse, Richardson Ave. at 5th St.
Oklahoma, McAlester 74501	Alexander M. Dinsmore (918 423-5030).	P.O. Box 816; 509 South 3d St.
Oklahoma City 73118	Charley W. Nease (405 231-4806)	Suite 404, 50 Penn Pl.
Tulsa 74135	Edward L. Johnson, Floyd L. Stelzer (918 581-7631).	6136 East 32nd Pl.
Oregon, Portland 97208	Jesse L. Colbert (503 234-4796)	P.O. Box 3202, 830 NE. Holladay St.
Texas, Freeport 77541	Vacant (713 233-2604)	P.O. Box 2006.
Utah, Salt Lake City 84138	Donald C. Alvord (801 524-5643). Edgar Guynn (801 524-5650). Jackson W. Moffitt (801 524-5646).	Rm. 8422, 8426, and 8432, Federal Bldg., 125 South State St.
Washington, D.C. 20006	William B. Gazdik, Harry A. Dupont, John A. Lees (acting) (202 343-4685).	Suite 316, 1825 K St., N.W.
Wyoming, Casper 82601	Charles J. Curtis (307 265-3407). Edward Haymaker (307 265-3247). Elmer M. Schell (307 265-3421).	P.O. Box 2859 and 2373; Rm. 2002 and 2001, Federal Bldg. and Post Office, 100 East B St.
Newcastle 82701	Glenn E. Worden (307 746-2737)	P.O. Box 219; Suite 201, 100½ West Main St.
Rock Springs 82901	John A. Fraher (307 362-6422). Arne A. Mattila (307 362-7350).	P.O. Box 1170; Rm. 201 and 204, First Security Bank Bldg., 502 South Front St.
Thermopolis 82443	George Kinsel (307 864-3477)	P.O. Box 590; Rm. 202, Federal Bldg.

EARTH RESOURCES OBSERVATION SYSTEMS PROGRAM

Location	*Official in charge and telephone number*	*Address*
Mississippi, Bay St. Louis 39521	Gary W. North (601 688-3541)	Bldg. 1100, National Space Technology Laboratories.
South Dakota, Sioux Falls 57198	Allen H. Watkins (605 594-6123)	EROS Data Center.

GEOLOGIC DIVISION

REGIONAL OFFICES

Location	*Official in charge and telephone number*	*Address*
Central Region: Denver, CO 80225	Ralph L. Erickson, Regional Geologist (303 234-3624).	Bldg. 25, Federal Center.
Eastern Region: Reston, VA 22092	Eugene H. Roseboom, Jr., Regional Geologist (703 860-6631).	953 National Center, 12201 Sunrise Valley Dr.
Western Region: Menlo Park, CA 94025	David L. Jones, Regional Geologist (415 323-2214).	345 Middlefield Rd.

OFFICES

Location	*Official in charge and telephone number*	*Address*
Alaska, Anchorage 99501	Donald H. Richter (907 344-2663)	216 Skyline Bldg., 218 E St.
College 99701	Florence R. Weber (907 479-7245)	P.O. Box 80586.
Arizona, Flagstaff 86001	Michael H. Carr (602 774-5261, ext. 1455).	601 East Cedar Ave.
Arkansas, Little Rock 72204	Boyd R. Haley (501 371-1616)	3815 West Roosevelt Rd.
California, La Jolla 92037	George W. Moore (714 453-2820)	P.O. Box 271; 8604 La Jolla Shores Dr.
San Francisco 94105	Ralph B. Matthiesen (415 556-7725)	Rm. 7067, 390 Main St.
Connecticut, Middletown 06457	Fred Pessl, Jr. (203 346-5542)	P.O. Box 470.
Florida, Miami 33139	E. A. Shinn (305 350-4239)	Fisher Island Station.
Hawaii, Hawaii National Park 96718	Robert I. Tilling (808 967-7485)	Hawaiian Volcano Observatory,
Kentucky, Lexington 40503	Wilds W. Olive (606 252-2552)	2035 Regency Rd.
Massachusetts, Boston 02110	M. H. Pease, Jr. (617 223-7202)	80 Broad St.
Woods Hole 02543	John C. Behrendt (617 548-8700)	U.S. Geological Survey, Woods Hole.
New Mexico, Albuquerque 87115	Jon R. Peterson (505 264-4637)	Albuquerque Seismological Center, Kirtland AFB, East Bldg. 10002.
Ohio, Columbus 43210	James M. Schopf (614 421-2393)	Orton Hall, Ohio State Univ., 155 South Oval Dr.
Pennsylvania, Carnegie 15106	Reginald P. Briggs (412 644-2920)	P.O. Box 420.
Puerto Rico, San Juan 00936	John M. Aaron (809 766-5340)	GPO Drawer 2230.
Tennessee, Knoxville 37902	Robert A. Laurence (615 524-4268).	301 West Cumberland Ave.
Texas, Corpus Christi 78411	Louis E. Garrison (512 888-3241)	P.O. Box 6732; Univ. of Corpus Christi.
Utah, Salt Lake City 84111	Lowell S. Hilpert (801 524-5640)	Rm. 8416, Federal Bldg., 125 South State St.
Washington, Seattle 98105	Thane H. McCulloh (206 543-5059)	Dept. of Oceanography, WB 10, Univ. of Washington.
Spokane 99201	Albert E. Weissenborn (509 456-4677).	West 920 Riverside Ave.
Wyoming, Laramie 82070	J. David Love (307 745-4495)	Box 3007, Univ. Station, Geology Hall, Univ. of Wyoming.

PUBLICATIONS DIVISION

PUBLIC INQUIRIES OFFICES

[Each of the following offices provides over-the-counter sales service for Survey book reports and geologic and topographic maps relating to its geographic area, and for selected Survey reports of general interest]

Location	*Official in charge and telephone number*	*Address*
Alaska, Anchorage 99501	Margaret I. Erwin (907 277-0577)	Rm. 108, Skyline Bldg., 508 2d Ave.
California, Los Angeles 90012	Lucy E. Birdsall (213 688-2850)	Rm. 7638, Federal Bldg., 300 North Los Angeles St.
San Francisco 94111	Jean V. Molleskog (415 556-5627)	Rm. 504, Custom House, 555 Battery St.
Colorado, Denver 80202	Sylvia T. Huhta (303 837-4169)	Rm. 1012, Federal Bldg., 1961 Stout St.
District of Columbia, Washington 20244.	Bruce A. Hubbard (202 343-8073)	Rm. 1028, General Services Bldg., 19th and F Sts., NW.
Texas, Dallas 75202	Mildred V. Smith (214 749-3230)	Rm. 1C45, Federal Bldg., 1100 Commerce St.
Utah, Salt Lake City 84138	Wendy R. Hassibe (801 524-5652)	Rm. 8102, Federal Bldg., 125 South State St.
Virginia, Reston 22092	A. Ernestine Jones (703 860-6167)	Rm. 1C402, National Center, 12201 Sunrise Valley Dr.
Washington, Spokane 99201	Eula M. Thune, (acting) (509 456-2524).	Rm. 678, U.S. Court House, West 920 Riverside Ave.

DISTRIBUTION CENTERS

[Survey maps are distributed by mail and over-the-counter from the following centers]

Location	*Official in charge and telephone number*	*Address*
Virginia, Arlington 22202 [1,2]	John J. Curry (703 557-2751)	1200 South Eads St.
Colorado, Denver 80225 [3]	Dwight F. Canfield (303 234-3832)	Box 25286, Federal Center.
Alaska, Fairbanks 99701 [4]	Natalie A. Cornforth, (907 452-1951, ext. 174).	310 First Ave.

TOPOGRAPHIC DIVISION

Location	*Official in charge and telephone number*	*Address*
California, Menlo Park 94025	Roy R. Mullen (415 323-2411)	345 Middlefield Rd.
Colorado, Denver 80225	Albert E. Letey (303 234-2351)	Bldg. 25, Federal Center.
Missouri, Rolla 65401	A. Carroll McCutchen (314 364-3680).	P.O. Box 133; 9th and Pine Sts.
South Dakota, Sioux Falls 57198	Allen H. Watkins (605 594-6123)	EROS Data Center.
Virginia, Reston 22090	Roy E. Fordham (703 471-1711)	1925 Newton Sq. East.
Reston 22092	Peter F. Bermel (703 860-6352)	567 National Center.

[1] For maps of areas east of the Mississippi River (including Minnesota).
[2] Also provides mail and over-the-counter distribution for Survey book reports.
[3] For maps of areas west of the Mississippi River (including Louisiana).
[4] For residents of Alaska.

WATER RESOURCES DIVISION

REGIONAL OFFICES

Location	*Official in charge and telephone number*	*Address*
Northeastern Region: Reston, VA 22092	Joseph T. Callahan, Regional Hydrologist (703 860-6985).	433 National Center, 12201 Sunrise Valley Dr.
Southeastern Region: Atlanta, GA 30309	Leslie B. Laird, Regional Hydrologist (404 526-5395).	Suite 200, 1459 Peachtree St. NE.
Central Region: Denver, CO 80225	Alfred Clebsch, Jr., Regional Hydrologist (303 234-3661).	Bldg. 25, Federal Center.
Western Region: Menlo Park, CA 94025	William H. Robinson (acting), Regional Hydrologist (415 323-8111).	345 Middlefield Rd.

DISTRICT OFFICES

Location	*Official in charge and telephone number*	*Address*
Alabama, Tuscaloosa 35486	William J. Powell (205 752-8104)	P.O. Box V; Rm. 202, Oil and Gas Board Bldg., Univ. of Alabama.
Alaska, Anchorage 99501	Harry Hulsing (907 277-5526, 5527)	Skyline Bldg., 218 E St.
Arizona, Tucson 85701	Horace M. Babcock (602 792-6671).	Federal Bldg., 301 W. Congress.
Arkansas, Little Rock 72201	Richard T. Sniegocki (501 378-5246).	Rm. 2301, Federal Office Bldg., 700 West Capitol Ave.
California, Menlo Park 94025	Lee R. Peterson (415 323-8111, ext. 2326, 2327, 2465, 2466).	855 Oak Grove Ave.
Colorado, Denver 80225	James E. Biesecker (303 234-5092)	Bldg. 53, Federal Center.
Connecticut, Hartford 06101	Frederick H. Ruggles, Jr. (203 244-2528).	P.O. Box 715; Rm. 235, Post Office Bldg., 135 High St.
Delaware	Walter F. White, Jr. (301 661-4664)	See Maryland District Office.
District of Columbia	do	Do.
Florida, Tallahassee 32303	Clyde S. Conover (904 386-1118)	Suite F-240, 325 John Knox Rd.
Georgia, Doraville 30340	John R. George (404 455-1211)	Suite B, 6481 Peachtree Industrial Blvd.
Hawaii, Honolulu 96815	Frank T. Hidaka (808 955-0251)	1833 Kalakaua Ave.
Idaho, Boise 83724	Hal K. Hall (208 342-2711, ext. 2537).	P.O. Box 036; Rm. 365, Federal Bldg. and U.S. Courthouse, 550 West Fort St.
Illinois, Champaign 61820	Lawrence A. Martens (217 359-3918).	P.O. Box 1026; 605 North Neil St.
Indiana, Indianapolis 46202	James L. Cook (317 269-7101)	1819 North Meridian St.
Iowa, Iowa City 52240	Sulo W. Wiitala (319 338-5521)	P.O. Box 1230; Rm. 269, Federal Bldg.
Kansas, Lawrence 66045	Joseph S. Rosenshein (913 864-4321).	1950 Avenue "A"—Campus West, Univ. of Kansas.
Kentucky, Louisville 40202	Robert V. Cushman (502 582-5241).	Rm. 572, Federal Bldg., 600 Federal Pl.
Louisiana, Baton Rouge 70806	Albert N. Cameron (504 387-0181, ext. 281).	P.O. Box 66492; 6554 Florida Blvd.
Maine	John A. Baker (617 223-2822)	See Massachusetts District Office.
Maryland, Parkville 21234	Walter F. White, Jr. (301 661-4664)	8809 Satyr Hill Rd.

Location	*Official in charge and telephone number*	*Address*
Massachusetts, Boston 02114	John A. Baker (617 223-2822)	Suite 1001, 150 Causeway St.
Michigan, Okemos 48864	T. Ray Cummings (517 372-1910, ext. 561).	2400 Science Parkway, Red Cedar Research Park.
Minnesota, St. Paul 55101	Charles R. Collier (612 725-7841, 7842).	Rm. 1033, Post Office Bldg.
Mississippi, Jackson 39206	Lamar E. Carroon (601 969-4600)	430 Bounds St.
Missouri, Rolla 65401	Anthony Homyk, Jr. (314 364-1599)	P.O. Box 340; 103 West 10th St.
Montana, Helena 59601	George M. Pike (406 442-9040, ext. 3263).	P.O. Box 1696; Rm. 421, Federal Bldg., 316 North Park Ave.
Nebraska, Lincoln 68508	Kenneth A. MacKichan (402 471-5082).	Rm. 127, Nebraska Hall, 901 North 17th St.
Nevada, Carson City 89701	John P. Monis (702 882-1388)	Rm. 229, Federal Bldg., 705 North Plaza St.
New Hampshire	John A. Baker (617 223-2822)	See Massachusetts District Office.
New Jersey, Trenton 08607	Harold Meisler (609 599-3511, ext. 212).	P.O. Box 1238; Rm. 420, Federal Bldg., 402 East State St.
New Mexico, Albuquerque 87106	William E. Hale (505 766-2246)	P.O. Box 4369; Geology Bldg., Univ. of New Mexico.
New York, Albany 12201	Robert J. Dingman (518 472-3107)	P.O. Box 1350; Rm. 343, U.S. Post Office and Courthouse.
North Carolina, Raleigh 27602	Ralph C. Heath (919 755-4510)	P.O. Box 2857; Rm. 440, Century Sta. Post Office Bldg.
North Dakota, Bismarck 58501	Walter R. Scott (701 255-4011, ext. 227, 228).	P.O. Box 778; Rm. 332, New Federal Bldg., 3d St. and Rosser Ave.
Ohio, Columbus 43212	James F. Blakey (614 469-5553)	975 West 3d Ave.
Oklahoma, Oklahoma City 73102	James H. Irwin (405 231-4256)	Rm. 621, 201 NW. 3d St.
Oregon, Portland 97208	Stanley F. Kapustka (503 234-3361, ext. 4776, 4777, 4778).	P.O. Box 3202; 830 NE. Holladay St.
Pennsylvania, Harrisburg 17108	Norman H. Beamer (717 782-3468)	P.O. Box 1107; 4th Floor, Federal Bldg., 228 Walnut St.
Puerto Rico, San Juan 00934	Ernest D. Cobb (809 783-4660)	P.O. Box 34168; Bldg. 652, Fort Buchanan.
Rhode Island	John A. Baker (617 223-2822)	See Massachusetts District Office.
South Carolina, Columbia 29201	John S. Stallings (803 765-5966)	Suite 200, 2001 Assembly St.
South Dakota, Huron 57350	John E. Powell (605 352-8651, ext. 293, 294).	P.O. Box 1412; Rm. 231, Federal Bldg.
Tennessee, Nashville 37203	Stanley P. Sauer (615 749-5424)	Rm. A-413, Federal Bldg., and U.S. Court House.
Texas, Austin 78701	I. Dale Yost (512 397-5766)	Rm. 630, Federal Bldg., 300 East 8th St.
Utah, Salt Lake City 84138	Theodore Arnow (801 524-5663)	Rm. 8002, Federal Bldg., 125 South State St.
Vermont	John A. Baker (617 223-2822)	See Massachusetts District Office.
Virginia, Richmond 23220	William E. Forrest (804 782-2427)	Rm. 304, 200 West Grace St.
Washington, Tacoma 98402	John F. McCall (206 593-6510)	Rm. 300, 1305 Tacoma Ave., South.
West Virginia, Charleston 25301	Edwin E. Harris (304 343-6181, ext. 310, 311, 339).	Rm. 3303, Federal Bldg. and U.S. Courthouse, 500 Quarrier St., East.
Wisconsin, Madison 53706	Charles L. R. Holt (608 262-2488).	Rm. 200, 1815 University Ave.
Wyoming, Cheyenne 82001	Samuel W. West (307 778-2220, ext. 2111).	P.O. Box 2087; 4015 Warren Ave.

OFFICES IN OTHER COUNTRIES

GEOLOGIC DIVISION

Location	*Officer in charge*	*Address*
Brazil, Rio de Janeiro	S. Anthony Stanin	U.S. Geological Survey, USAID/Rio de Janeiro/ENGR, APO New York 09676.

Location	*Officer in charge*	*Address*
Colombia, Bogota	Maurice M. Brock	U.S. Geological Survey, USAID, c/o American Embassy, APO New York 09895.
Indonesia, Bandung	Paul W. Richards	U.S. Geological Survey, c/o American Embassy, USAID/ENGR, APO San Francisco 96356.
Saudi Arabia, Jiddah	Thor H. Kiilsgaard	U.S. Geological Survey, c/o American Embassy, APO New York 09697.
Thailand, Bangkok	Joseph O. Morgan	Office of Agricultural Development, USOM--Thailand, APO San Francisco 96346.

WATER RESOURCES DIVISION

Location	*Officer in charge*	*Address*
Kenya, Nairobi	Neal E. McClymonds	U.S. AID/Nairobi, U.S. Dept. of State, Washington, DC 20521.
Yemen, Şan'a'	G. Chase Tibbitts, Jr.	U.S. Geological Survey, USAID/Şan'a', Agency for International Development, Washington, DC 20521.

INVESTIGATIONS IN PROGRESS IN THE GEOLOGICAL SURVEY

Investigations in progress during fiscal year 1975 are listed below, together with the names and headquarters of the individuals in charge of each. Headquarters at main centers are indicated by (NC) for the National Center in Reston, Va., (D) for Denver, Colo., and (M) for Menlo Park, Calif.; headquarters in other cities are indicated by name (see list of offices, p. , 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, Reston, Va. 22092. The lowercase letter after the name of the project leader shows the Division technical responsibility: c, Conservation Division; l, Land Information Analysis; 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 1:62,500 (for example, 1:250,000), and mapping at scales of 1:62,500, or larger (for example, 1:24,000).

Abstracts. *See* **Bibliographies and abstracts.**
Aluminum:
- Resources of the United States (S. H. Patterson, NC)

Analytical chemistry:
- Activation analysis (J. J. Rowe, NC)
- Analytical methods:
  - Textural automatic image analyzer research (M. B. Sawyer, D)
  - Water chemistry (M. W. Skougstad, w, D)
- Analytical services and research (J. I. Dinnin, NC; C. Huffman, Jr., D; C. O. Ingamells, M)
- Assessment of neutron activation methods (V. J. Janzer, w, D)
- Instrumentation (J. F. Abell, NC)
- Mineral deposits, characteristic analysis (J. M. Botbol, NC)
- Natural organic, macromolecules in water (R. L. Wershaw, w, D)
- Organic geochemistry and infrared analysis (I. A. Breger, NC)
- Organic substances in water (D. F. Goerlitz, w, M)
- Plant laboratory support (J. J. Connor, D)
- Radioactivation and radiochemistry (H. T. Millard, D)
- Reactor support (G. P. Kraker, Jr., w, D)
- Rock chemical analysis:
  - General (D. R. Norton, D)
  - Rapid (L. Shapiro, NC)
- Sample control (Harry Bastron, M)
- Services (L. B. Riley, D)
- Spectrochemistry (E. L. Mosier, D)
- Trace analysis methods, research (F. N. Ward, D)
- Ultratrace analysis (H. T. Millard, D)
- X-ray spectrometer for Viking lander (P. Toulmin III, NC)
- *See also* Spectroscopy.

Arctic engineering geology (Reuben Kachadoorian, M)
Barite:
- Geology, geochemistry, and resources of barite (D. A. Brobst, NC)

Base metals. *See base-metal names.*
Bibliographies and abstracts:
- Geophysical abstracts (J. W. Clarke, NC)
- Lunar bibliography (J. H. Freeberg, M)
- Vanadium, geology and resources, bibliography (J. P. Ohl, D)

Borates:
- California:
  - Furnace Creek area (J. F. McAllister, M)
  - Searles Lake area (G. I. Smith, M)

Chromite. *See* Ferro-alloy metals.
Clays:
- Bentonite, resource evaluation in Rocky Mountain region (C. A. Wolfbauer, D)
- *State:*
- Georgia, kaolin investigations (S. H. Patterson, NC)

Coal:
- Resources of the United States (Paul Averitt, D)
- *States:*
- Alaska:
  - Bering River coal field (R. B. Sanders, c, Anchorage)
  - Cape Beaufort-Corwin Bluff coal field (J. E. Callahan, c, Anchorage)
  - Kukpowruk River coal field (J. E. Callahan, c, Anchorage)
  - Nenana (C. Wahrhaftig, M)
- Colorado:
  - Brook Cliffs coal field (G. D. Fraser, c, D)
  - Buckhorn Lakes quadrangle (R. G. Dickinson, c, D)

Coal—Continued
States—Continued
Colorado—Continued
Citadel Plateau (G. A. Izett, c, D)
Courthouse Mountain quadrangle (R. G. Dickinson, c, D)
Danforth Hills area (M. J. Reheis, c, D)
Denver basin, Tertiary coal zone (P. E. Soister, c, D)
Disappointment Valley, eastern (D. E. Ward, D)
Douglas Creek Arch area (B. E. Barnum, c, D)
Little Snake River coal field (C. S. V. Barclay, c, D)
Middle Park—North Park area (G. A. Izett, c, D)
North Park area (D. Hill, c, D)
Savery quadrangle (C. S. V. Barclay, c, D)
Smizer Gulch and Rough Gulch quadrangles (W. J. Hail, D)
Washboard Rock quadrangle (R. G. Dickinson, c, D)
Watkins and Watkins SE quadrangles (P. E. Soister, c, D)
Yampa coal field (M. E. Brownfield, c, D)
Montana:
Decker quadrangle (B. E. Law, c, Casper, Wyo.)
Hardy quadrangle (K. S. Soward, c, Casper, Wyo.)
Jordan quadrangle (G. D. Mowat, c, Billings)
Monarch quadrangle (B. E. Barnum, c, D)
Pearl School quadrangle (B. E. Law, c, Casper, Wyo.)
Rocky Reef quadrangle (K. S. Soward, c, Casper, Wyo.)
New Mexico:
Gallup East quadrangle (E. D. Patterson, c, Roswell)
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.)
North Almont quadrangle (H. L. Smith, c, D)
White Butte 15-minute quadrangle (K. S. Soward, c, Casper, Wyo.)
Pennsylvania (NC):
Northern anthracite field (M. J. Bergin)
Southern anthracite field (G. H. Wood, Jr.)
Utah (c, D, except as otherwise noted):
Alton coal field (W. E. Bowers)
Basin Canyon quadrangle (Fred Peterson)
Big Hollow Wash quadrangle (Fred Peterson)
Blackburn Canyon quadrangle (Fred Peterson)
Butler Valley quadrangle (W. E. Bowers)
Canaan Peak quadrangle (W. E. Bowers)
Collet Top quadrangle (H. D. Zeller)
East-of-the-Navajo quadrangle (Fred Peterson)
Fourmile Bench quadrangle (W. E. Bowers)
Horse Mountain quadrangle (W. E. Bowers)
Jessen Butte quadrangle (E. M. Schell, c, Casper, Wyo.)
Kaiparowits Plateau area (H. D. Zeller)
Needle Eye Point quadrangle (H. D. Zeller)
Pete's Cove quadrangle (H. D. Zeller)
Ship Mountain Point quadrangle (H. D. Zeller)
Sooner Bench quadrangle (Fred Peterson)
Sunset Flat quadrangle (Fred Peterson)
Virginia and West Virginia, Central Appalachian Basin (K. J. Englund, NC)

Coal—Continued
States—Continued
Wyoming:
Acme quadrangle (B. E. Law, c, Casper)
Alpine quadrangle (H. F. Albee, c, Salt Lake City, Utah)
Appel Butte quadrangle (G. L. Galyardt, c, D)
Bailey Lake quadrangle (M. L. Schroeder, c, D)
Browns Hill quadrangle (C. S. V. Barclay, c, D)
Bull Creek quadrangle (M. L. Schroeder, c, D)
Cottonwood Rim quadrangle (C. S. V. Barclay, c, D)
Coyote Draw quadrangle (G. L. Galyardt, c, D)
Creston Junction quadrangle (R. B. Sanders, c, D)
Deer Creek quadrangle (D. A. Jobin, c, D)
Fortin Draw quadrangle (B. E. Law, c, Casper)
Four Bar—J Ranch quadrangle (G. L. Galyardt, c, D)
Gillette Coal Field (W. L. Rohrer, c, Casper)
Gillette East quadrangle (B. E. Law, c, Casper)
Gillette West quadrangle (B. E. Law, c, Casper)
Greenhill quadrangle (S. P. Buck, c, Casper)
Grieve Reservoir quadrangle (C. S. V. Barclay, c, D)
Hanna Basin area (L. F. Blanchard, c, D)
Kemmerer area (M. L. Schroeder, c, D)
Ketchum Buttes quadrangle (C. S. V. Barclay, c, D)
Little Snake River coal field (C. S. V. Barclay, c, D)
Monarch quadrangle (B. E. Barnum, c, D)
Oil Mountain quadrangle (W. H. Laraway, c, Casper)
Oriba quadrangle (B. E. Law, c, Casper)
Pickle Pass quadrangle (D. A. Jobin, c, D)
Pleasantdale quadrangle (S. L. Grazis, c, D)
Poison Spider quadrangle (W. H. Laraway, c, Casper)
Ranchester quadrangle (B. E. Barnum, c, D)
Rawlins—Baggs area (G. M. Edson, c, D)
Reid Canyon (W. H. Laraway, c, Casper)
Riner quadrangle (R. B. Sanders, c, D)
Rock Springs uplift (P. J. LaPoint, c, D)
Saddlehorse Butte quadrangle (S. L. Grazis, c, D)
Savery quadrangle (C. S. V. Barclay, c, D)
Scraper Reservoir quadrangle (S. L. Grazis, c, D)
Sheridan Pass quadrangle (W. L. Rohr. Rohrer, c, Casper)
Ship Mountain Point quadrangle (H. D. Zeller, c, D)
Stewart Peak quadrangle (D. A. Jobin, c, D)
The Gap quadrangle (G. L. Galyardt, c, D)
The Gap southwest quadrangle (S. L. Grazis, C, D)
Tullis quadrangle (C. S. V. Barclay, c, D)
Weston southwest quadrangle (R. W. Jones, c, Casper)

Construction and terrain problems:
Electronics instrumentation research for engineering geology (J. B. Bennetti, D)
Engineering geology laboratory (R. A. Farrow, D)
Geotechnical measurements and services (H. W. Olsen, D)
Plowshare special studies (F. W. Stead, D)
Reactor hazards research (K. L. Pierce, D)
Reactor site investigations (R. H. Morris, D)
Regional slope-stability studies, California and Pennsylvania (D. H. Radbruch-Hall, M)
Research in rock mechanics (F. T. Lee, D)
Sino-Soviet terrain (L. D. Bonham, NC)
Soil engineering research (T. L. Youd, M)
Special intelligence (L. D. Bonham, NC)
Subsurface waste emplacement (Harley Barnes, D)
Volcanic hazards (D. R. Crandell, D)

Ferro-alloy metals:
Chromium resource studies (T. P. Thayer, NC)
Molybdenum, Maine and New Hampshire, with porphyry copper (R. G. Schmidt, NC)
Molybdenum-rhenium resource studies (R. U. King, D)
Tungsten, North Carolina, Hamme district (J. E. Gair, NC)
State:
Oregon, John Day area (T. P. Thayer, NC)

Flood characteristics of streams at selected sites:
Alabama, flood studies and bridge-site investigations (C. O. Ming, w, Montgomery)
Iowa, flood information at selected bridge sites (O. G. Lara, w, Iowa City)
New Mexico, peak flood-flow characteristics of small streams (A. G. Scott, w, Santa Fe)
Oregon, flood profiles, Umpqua River and tributaries (D. D. Harris, w, Portland)
Tennessee (W. J. Randolph, w, Nashville)

Flood discharge from small drainage areas:
Colorado (G. L. Ducret, Jr., w, D)
Connecticut (M. D. Thomas, w, Hartford)
Delaware (R. H. Simmons, w, Dover)
Florida (W. C. Bridges, w, Tallahassee)
Illinois (J. W. Curtis, w, Champaign)
Maryland (D. H. Carpenter, w, College Park)
Massachusetts (C. G. Johnson, Jr., w, Boston)
Minnesota (L. C. Guetzkow, w, St. Paul)
Mississippi (B. E. Colson, w, Jackson)
Rhode Island (C. G. Johnson, Jr., w, Boston, Mass.)
Virginia (E. M. Miller, w, Richmond)

Flood frequency:
Alabama, flood frequency synthesis for small streams (C. O. Ming, w, Montgomery)
Iowa (O. G. Lara, w, Iowa City)
Kentucky, magnitude and frequency (C. H. Hannum, w, Louisville)
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, Jr., w, Raleigh)

Flood hazard mapping:
United States (E. J. Kennedy, w, NC)
Alabama (J. R. Harkins, w, Tuscaloosa)
Arkansas (M. S. Hines, w, Little Rock)
California (J. R. Crippen, w, M)
Colorado (J. F. McCain, w, D)
Florida (S. D. Leach, w, Tallahassee)
Connecticut (F. H. Ruggles, w, Hartford)
Georgia (McGlone Price, w, Doraville)
Hawaii (C. J. Ewart, w, Honolulu)
Illinois (J. D. Camp, w, Champaign)
Indiana (J. B. Swing, w, Indianapolis)
Louisiana (A. S. Lowe, w, Baton Rouge)
Maine (R. A. Morrill, w, Augusta)
Maryland (W. B. Solley, w, Parkville)
Massachusetts (S. W. Wandle, Jr., w, Boston)
Michigan (R. L. Knutilla, w, Okemos)
Minnesota (L. C. Guetzkow, w, St. Paul)
Mississippi (K. V. Wilson, w, Jackson)
Missouri (E. E. Gann, w, Rolla)
Montana (M. V. Johnson, w, Helena)

Flood hazard mapping—Continued
Nebraska (F. B. Shaffer, w, Lincoln)
Nevada (D. O. Moore, w, Carson City)
New Hampshire (S. W. Wandle, Jr., w, Boston)
North Carolina (K. L. Lindskov, w, Raleigh)
North Dakota (O. A. Crosby, w, Bismarck)
Oklahoma (W. B. Mills, w, Oklahoma City)
Oregon (D. D. Harris, w, Portland)
Pennsylvania (L. V. Page, w, Harrisburg)
Puerto Rico (W. J. Haire, w, San Juan)
South Carolina (W. T. Utter, w, Columbia)
South Dakota (O. J. Larimer, w, Huron)
Tennessee (C. R. Gamble, w, Nashville)
Texas (J. D. Bohn, w, Austin)
Vermont (S. W. Wandle, Jr., w, Boston)
Virginia (E. M. Miller, w, Richmond)
West Virginia (G. S. Runner, w, Charleston)
Wisconsin (C. L. Lawrence, w, Madison)
Wyoming (J. F. Wilson, Jr., w, Cheyenne)

Flood insurance studies:
Alabama (J. R. Harkins, w, Tuscaloosa)
Arizona (B. N. Aldridge, w, Tucson)
California (J. R. Crippen, w, M)
Colorado (R. U. Grozier, w, D)
Connecticut (M. A. Cervione, w, Hartford)
Florida (S. D. Leach, w, Tallahassee)
Illinois (A. W. Noehre, w, Oak Park)
Indiana (P. B. Rohne, Jr., w, Indianapolis)
Iowa (A. J. Heinitz, w, Iowa City)
Kansas (D. B. Richards, w, Lawrence)
Louisiana (F. N. Lee, w, Baton Rouge)
Michigan (R. L. Knutilla, w, Okemos)
Minnesota (L. C. Guetzkow, w, St. Paul)
Missouri (E. E. Gann, w, Rolla)
Nebraska (G. G. Jamison, w, Lincoln)
New Jersey (E. G. Miller, w, Trenton)
New York (K. I. Darmer, w, Albany)
Ohio (D. K. Roth, w, Columbus)
Oklahoma (T. L. Huntzinger, w, Oklahoma City)
Oregon (D. D. Harris, w, Portland)
Pennsylvania (L. V. Page, w, Harrisburg)
Puerto Rico (W. J. Haire, w, San Juan)
South Carolina (B. H. Whetstone, w, Columbia)
Texas (J. D. Bohn, w, Austin)
Washington (E. G. Nassar, w, Tacoma)
Wisconsin (W. B. Gannon, w, Madison)

Flood-inundation mapping:
Idaho (W. A. Harenberg, w, Boise)
Illinois, northeastern (A. W. Noehre, w, Oak Park)

Flood investigations:
Documentation extreme floods (H. H. Barnes, Jr., w, NC)
States:
Arkansas (M. S. Hines, w, Little Rock)
California, Lake-Playa flood study (M. W. Busby, w, Laguna Niguel)
Colorado, flood plain mapping (J. F. McCain, w, D)
Florida (w, Tampa):
Flood hazard evaluation, Myakka River (W. R. Murphy, Jr.)
Flood plain mapping (W. R. Murphy, Jr.)

Geochemistry and petrology, field studies—Continued
States—Continued
Nevada, igneous rocks and related ore deposits (M. L. Silberman, M)
New Mexico, Valles Mountains (R. L. Smith, NC)
South Dakota, Keystone pegmatite area (J. J. Norton, Rapid City)

Geochronological investigations:
Carbon-14 method (Meyer Rubin, NC)
Geochronology—Denver (C. E. Hedge, D)
Geochronology and rock magnetism (G. B. Dalrymple, M)
Geochronology of uranium ores and their host rocks (K. R. Ludwig, D)
Igneous rocks and deformational periods (R. W. Kistler, M)
Lead-uranium, lead-thorium, and lead-alpha methods (T. W. Stern, NC)
Magnetic chronology, Colorado Plateau and environs (D. P. Elston, E. M. Shoemaker, Flagstaff, Ariz.)
Radioactive-disequilibrium studies (J. N. Rosholt, D)
State:
Alaska, K—Ar dates, Southwest Brooks Range (I. L. Tailleur, M; R. B. Forbes, D. L. Turner, Fairbanks)
See also Isotope and nuclear studies.

Geologic mapping:
Geologic map of the United States (P. B. King, M)
Map scale smaller than 1:62,500:
Antarctica:
Dufek Massif and Forrestal Range, Pensacola Mountains (A. B. Ford, M)
Neptune and Patuxent ranges, Pensacola Mountains (D. L. Schmidt, D)
Belt basin study (J. E. Harrison, D)
Columbia River basalt (D. A. Swanson, M)
States:
Alaska (M, except as otherwise noted):
Ambler River and Baird Mountains quadrangles (I. L. Tailleur, M)
Charley River quadrangle (E. E. Brabb)
Compilations of Alaska geology (E. H. Lathram)
Craig quadrangle (G. D. Eberlein, Michael Churkin, Jr.)
Delong Mountains quadrangle (I. L. Tailleur)
Geologic map (H. M. Beikman)
Geology of Alaska (George Gryc)
Glacier Bay National Monument (D. A. Brew)
Hughes-Shungnak area (W. W. Patton, Jr.)
Iliamna quadrangle (R. L. Detterman)
Juneau and Taku River quadrangles (D. A. Brew)
Metamorphic facies map (D. A. Brew)
Natural landmarks investigation (R. L. Detterman)
Northern part, petroleum investigations (George Gryc)
St. Lawrence Island (W. W. Patton, Jr.)
Tracy Arm-Fords Terror (Thundering Fiords) Wilderness study area (D. A. Brew)
Arizona (Flagstaff):
North-central part (D. P. Elston)
Phoenix 2-degree quadrangle (T. N. V. Karlstrom)
Shivwits Plateau (Ivo Lucchitta)
Arkansas (B. R. Haley, Little Rock)
Colorado (D):
Denver 2-degree quadrangle (B. H. Bryant)

Geologic mapping—Continued
Map scale smaller than 1:62,500—Continued
States—Continued
Colorado—Continued
Geologic map (O. L. Tweto)
Leadville 2-degree quadrangle (O. L. Tweto)
Montrose 2-degree quadrangle (W. J. Hail, Jr.)
Pueblo 2-degree quadrangle (G. R. Scott)
Sterling 2-degree quadrangle (J. A. Sharps)
Idaho (D, except as otherwise noted):
Challis Volcanics (D. H. McIntyre)
Dubois 2-degree quadrangle (D. L. Schleicher)
Idaho Falls 2-degree quadrangle (D. L. Schleicher)
Preston 2-degree quadrangle (S. S. Oriel)
Snake River plain, central part, volcanic petrology (H. E. Malde)
Snake River plain region, eastern part (S. S. Oriel)
Spokane-Wallace region (A. B. Griggs, M)
Montana:
Butte 2-degree quadrangle (M. R. Klepper, NC)
Spokane-Wallace region (A. B. Griggs, M)
Nevada:
Elko County (R. A. Hope, M)
Elko County, central (K. B. Ketner, D)
Elko County, western (R. R. Coats, M)
Geologic map (J. H. Stewart, M)
Nevada Test Site geologic investigations (P. P. Orkild, D)
New Mexico (D):
North Church Rock area (A. R. Kirk)
Sanostee (A. C. Huffman, Jr.)
Socorro 2-degree quadrangle (G. O. Bachman)
West half of Santa Fe 2-degree quadrangle (E. H. Baltz, Jr.)
Pennsylvania, Greater Pittsburgh region geology (W. R. Wagner, Carnegie)
Utah:
Delta 2-degree quadrangle (H. T. Morris, M)
Glen Canyon Recreation Area (A. L. Brokaw, D)
Tooele 2-degree quadrangle (W. J. Moore, M)
Washington, Spokane-Wallace region (A. B. Griggs, M)
Wyoming:
Geologic map (J. D. Love, D)
Preston 2-degree quadrangle (S. S. Oriel, D)
Map scale 1:62,500, and larger:
States and territories:
Alaska:
Anatuvuk Pass (R. B. Sanders, c, Anchorage)
Anchorage area (Ernest Dobrovolny, D)
Bering River coal field (R. B. Sanders, c, Anchorage)
Cape Beaufort-Corwin Bluffs coal field (J. E. Callahan, c, Anchorage)
Geology and mineral resources of the Ketchikan quadrangle (H. C. Berg, M)
Juneau area (R. D. Miller, D)
Kukpowruk River coal field (J. E. Callahan, c, Anchorage)
Nelchina area Mesozoic investigations (Arthur Grantz, M)
Nenana coal investigations (Clyde Wahrhaftig, M)
Nome area (C. L. Hummel, M)

Geologic mapping—Continued
Map scale 1:62,500 and larger—Continued
States and territories—Continued
Arizona:
Bowie zeolite area (L. H. Godwin, c, NC)
Cochise County, southern part (P. T. Hayes, D)
Cummings Mesa quadrangle (Fred Peterson, c, D)
Garnet Mountain quadrangle (P. M. Blacet, M)
Hackberry Mountain area (D. P. Elston, Flagstaff)
Mt. Wrightson quadrangle (H. D. Drewes, D)
Ray district, porphyry copper (H. R. Cornwall, M)
Sedona area (D. P. Elston, Flagstaff)
California (M, except as otherwise noted):
Coast Range, ultramafic rocks (E. H. Bailey)
Condrey Mountain-Hornbrook quadrangle (P. E. Hotz)
Geysers-Clear Lake area (R. J. McLaughlin)
Long Valley caldera (R. A. Bailey, NC)
Malibu Beach and Topanga quadrangles (R. F. Yerkes)
Merced Peak quadrangle (D. L. Peck, NC)
Palo Alto, San Mateo, and Montara Mountain quadrangles (E. H. Pampeyan)
Point Dume and Triunfo Pass quadrangles (R. H. Campbell)
Ryan quadrangle (J. F. McAllister)
Searles Lake area (G. I. Smith)
Sierra Nevada batholith (P. C. Bateman)
Colorado:
Barcus Creek quadrangle (W. J. Hail, D)
Barcus Creek SE quadrangle (W. J. Hail, D)
Bonanza quadrangle (R. E. Van Alstine, NC)
Buckhorn Lakes quadrangle (R. G. Dickinson, c, D)
Central City area (R. B. Taylor, D)
Citadel Plateau (G. A. Izett, c, D)
Coal mine deformation studies, Somerset mining district (C. R. Dunrud, D)
Cochetopa area (J. C. Olson, D)
Courthouse Mountain quadrangle (R. G. Dickinson, c, D)
Denver basin, Tertiary coal zone (P. E. Soister, c, D)
Denver metropolitan area (R. M. Lindvall, D)
Disappointment Valley, geology and coal resource (D. E. Ward, D)
Front Range, northeastern part, Fort Collins area (W. A. Braddock, D)
Indian Hills Precambrian (B. H. Bryant, D)
Lake City caldera (P. W. Lipman, D)
Middle Park—North Park area (G. A. Izett, c, D)
Northern Park Range (G. L. Snyder, D)
Philadelphia Creek quadrangle (B. E. Barnum, c, D)
Platoro caldera and related volcanic rocks, southeastern San Juan Mountains (P. W. Lipman, D)
Poncha Springs quadrangle (R. E. Van Alstine, NC)
Rangely NE quadrangle (H. L. Cullins, c, Metairie, La.)
Rough Gulch quadrangle (W. J. Hail, D)
San Juan mining area (R. G. Luedke, NC)
Savery quadrangle (C. S. V. Barclay, c, D)
Smizer Gulch quadrangle (W. J. Hail, D)
Strasburg SW quadrangle (P. E. Soister, c, D)
Thornburgh quadrangle (M. J. Reheis, c, D)
Ward and Gold Hill quadrangles (D. J. Gable, D)
Washboard Rock quadrangle (R. G. Dickinson, c, D)

Geologic mapping—Continued
Map scale 1:62,500 and larger—Continued
States and territories—Continued
Colorado—Continued
Watkins and Watkins SE quadrangles (P. E. Soister, c, D)
Connecticut:
Cooperative mapping program (M. H. Pease, Jr., Boston, Mass.)
Taconic sequence (E-an Zen, NC)
Florida, Attapulgus-Thomasville area, fuller's earth deposits (S. H. Patterson, NC)
Idaho:
Alpine quadrangle (H. F. Albee, c, Salt Lake City, Utah)
Bayhorse area (S. W. Hobbs, D)
Boulder Mountains (C. M. Tschanz, D)
Goat Mountain quadrangle (M. H. Staatz, D)
Grouse quadrangle (B. A. Skipp, D)
Hawley Mountain quadrangle (W. J. Mapel, D)
Malad southeast quadrangle (S. S. Oriel, D)
Montour quadrangle (H. E. Malde, D)
Palisades Dam quadrangle (D. A. Jobin, c, D)
Patterson quadrangle (E. T. Ruppel, D)
Poker Peak quadrangle (H. F. Albee, c, Salt Lake City, Utah)
Upper and Lower Red Rock Lakes quadrangles (I. J. Witkind, D)
Wood River district (W. E. Hall, M)
Yellow Pine quadrangle (B. F. Leonard, D)
Indiana:
Ohio River Quaternary (M. P. Weiss, DeKalb, Ill.)
Ohio River valley, Quaternary geology (L. L. Ray, NC)
Kentucky, cooperative mapping program (D. W. Olive, Lexington)
Maine (NC, except as otherwise noted):
Blue Hill quadrangle (D. B. Stewart)
Castine quadrangle (D. B. Stewart)
Chain Lakes area (E. L. Boudette)
Orland quadrangle (D. R. Wones)
Rumford quadrangle (R. H. Moench, D)
The Forks quadrangle (F. C. Canney, D)
Maryland (NC):
Delmarva Peninsula (J. P. Owens)
Northern Coastal Plain (J. P. Minard)
Western Maryland Piedmont (M. W. Higgins)
Massachusetts (Boston, except as otherwise noted):
Boston and vicinity (C. A. Kaye)
Cooperative mapping program (M. H. Pease, Jr.)
Taconic sequence (E-an Zen, NC)
Michigan (NC):
Gogebic Range, western part (R. G. Schmidt)
Wakefield quadrangle (W. C. Prinz)
Montana:
Bearpaw Mountains, petrology (B. C. Hearn, Jr., NC)
Boulder Batholith region (H. W. Smedes, D)
Butte North quadrangle (H. W. Smedes, D)
Cooke City quadrangle (J. E. Elliott, D)
Craig quadrangle (R. G. Schmidt, NC)
Crazy Mountains Basin (B. A. Skipp, D)
Decker quadrangle (B. E. Law, c, Casper, Wyo.)
Diatremes, Missouri River Breaks (B. C. Hearn, Jr., NC)

Geologic mapping—Continued
Map scale 1:62,500 and larger—Continued
States and territories—Continued
Montana—Continued
Elk Park quadrangle (H. W. Smedes, D)
Hardy quadrangle (K. S. Soward, c, Casper, Wyo.)
Jordan quadrangle (G. D. Mowat, c, Billings)
Lemhi Pass quadrangle (M. H. Staatz, D)
Melrose phosphate field (G. D. Fraser, c, D)
Monarch quadrangle (B. E. Barnum, c, D)
Northern Pioneer Range, geologic environment (E-an Zen, NC)
Pearl School quadrangle (G. L. Galyardt, c, Casper, Wyo.)
Rocky Reef quadrangle (K. S. Soward, c, Casper, Wyo.)
Wickiup Creek quadrangle (H. W. Smedes, D)
Wolf Creek area, petrology (R. G. Schmidt, NC)
Nevada:
Austin quadrangle (E. H. McKee, M)
Bellevue Peak quadrangle (T. B. Nolan, NC)
Carlin region (J. F. Smith, Jr., D)
Jordan Meadow and Disaster Peak quadrangles (R. C. Greene, M)
Kobeh Valley (T. B. Nolan, NC; C. W. Merriam, M)
Midas-Jarbidge area (R. R. Coats, M)
Pinto Summit quadrangle (T. B. Nolan, NC)
Spruce Mountain 4 quadrangle (G. D. Fraser, c, D)
New Hampshire, cooperative mapping program, surficial (Carl Koteff, Boston, Mass.)
New Mexico:
Acoma area (C. H. Maxwell, D)
Apache Springs and Galisteo quadrangles (R. B. Johnson, D)
Church Rock-Smith Lake (C. T. Pierson, D)
Cretaceous stratigraphy, San Juan basin (E. R. Landis, D)
Gallup East quadrangle (E. D. Patterson, c, Roswell)
Gallup West quadrangle (J. E. Fassett, c, Farmington)
Hillsboro quadrangle (D. C. Hedlund, D)
Iron Mountain (A. V. Heyl, Jr., D)
Manuelito quadrangle (J. E. Fassett, c, Farmington)
Manzano Mountains (D. A. Myers, D)
Pinos Altos Range (T. L. Finnell, D)
Raton coal basin, western part (C. L. Pillmore, D)
Samson Lake quadrangle (J. E. Fassett, c, Farmington)
Twin Butte quadrangle (J. E. Fassett, c, Farmington)
Valles Mountains, petrology (R. L. Smith, NC)
New York (NC):
Pope Mills and Richville quadrangles (C. E. Brown)
Taconic sequence (E-an Zen)
North Carolina, Central Piedmont (A. A. Stromquist, D)
North Dakota:
Clark Butte 15-minute quadrangle (G. D. Mowat, c, Billings, Mont.)
North Almont quadrangle (H. L. Smith, c, D)
White Butte 15-minute quadrangle (K. S. Soward, c, Casper, Wyo.)
Pennsylvania (NC):
Claysville-Avella area (S. P. Schweinfurth)
Northern anthracite field (M. J. Bergin)
Southern anthracite field (G. H. Wood, Jr.)

Geologic mapping—Continued
Map scale 1:62,500 and larger—Continued
States and territories—Continued
Pennsylvania—Continued
Western middle anthracite field (H. H. Arndt)
Wind Gap and adjacent quadrangles (J. B. Epstein)
Puerto Rico (J. M. Aaron, San Juan)
South Dakota:
Black Hills Precambrian (J. A. Redden, Hill City)
Keystone Pegmatite area (J. J. Norton, NC)
Rapid City area (J. M. Cattermole, D)
Texas, Tilden-Loma Alta area (K. A. Dickinson, D)
Utah:
Basin Canyon quadrangle (Fred Peterson, c, D)
Big Hollow Wash quadrangle (Fred Peterson, c, D)
Blackburn Canyon quadrangle (Fred Peterson, c, D)
Butler Valley quadrangle (W. E. Bowers, c, D)
Canaan Peak quadrangle (W. E. Bowers, c, D)
Coal-mine bumps, Sunnyside mining district (F. W. Osterwald, D)
Collet Top quadrangle (H. D. Zeller, c, D)
Confusion Range (R. K. Hose, M)
Crawford Mountains (W. C. Gere, c, M)
East-of-the-Navajo quadrangle (Fred Peterson, c, D)
Fourmile Bench quadrangle (W. E. Bowers, c, D)
Horse Mountain quadrangle (W. E. Bowers, c, D)
Jessen Butte quadrangle (E. M. Schell, c, Casper, Wyo.)
Matlin Mountains (V. R. Todd, M)
Needle Eye Point quadrangle (H. D. Zeller, c, D)
Oak City area (D. J. Varnes, D)
Ogden 4 NW quadrangle (R. J. Hite, c, D)
Pete's Cove quadrangle (H. D. Zeller, c, D)
Salt Lake City and vicinity (Richard VanHorn, D)
Seep Flat quadrangle (E. V. Stephens, c, M)
Sheeprock Mountains, West Tintic district (H. T. Morris, M)
Ship Mountain Point quadrangle (H. D. Zeller, c, D)
Sooner Bench quadrangle (Fred Peterson, c, D)
Sunset Flat quadrangle (Fred Peterson, c, D)
Upper Valley quadrangle (W. E. Bowers, c, D)
Wah Wah Summit quadrangle (L. F. Hintze, Salt Lake City)
Wide Hollow Reservoir (E. V. Stephens, c, M)
Willard Peak area (M. D. Crittenden, Jr., M)
Virginia (NC):
Culpepper Basin (K. Y. Lee)
Delmarva Peninsula (J. P. Owens)
Northern Blue Ridge (G. H. Espenshade)
Rapidan-Rappahannock (Louis Pavlides)
Washington:
Chewelah No. 4 quadrangle (F. K. Miller, M)
Glacier Park area (F. W. Cater, D)
Loomis quadrangle (C. D. Rinehart, M)
Olympic Peninsula, eastern part (W. M. Cady, D)
Olympic Peninsula, northwestern part (P. D. Snavely, Jr., M)
Stevens County (R. G. Yates, M)
Wisconsin:
Black River Falls and Hatfield quadrangles (Harry Klemic, NC)
Lead-zinc district (W. S. West, Platteville)

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- Rocky Mountains, northern (D. L. Peterson, M. D. Kleinkopf, D)
- Southeastern States geophysical studies (Peter Popenoe, NC)
- Southwestern States geophysical studies (D. L. Peterson, NC)
- Ultramafic rocks, geophysical studies, intrusions (G. A. Thompson, M)
- United States, aeromagnetic surveys (E. R. King, NC)
- Yellowstone National Park, geophysical study (H. R. Blank, Eugene, Oreg.)
- *States and territories:*
- Alaska, Ambler River and Baird Mountains quadrangles gravity (D. F. Barnes, M)
- California, Sierra Nevada, geophysical studies (H. W. Oliver, M)
- Idaho, Snake River Plain (D. L. Peterson, D)
- Maryland, Cooperative Survey (J. L. Meuschke, D)
- Massachusetts:
  - Cooperative survey (J. L. Meuschke, D)
  - Geophysical studies (M. F. Kane, NC)
- Minnesota (NC):
  - Keweenawan rocks, magnetic studies (K. G. Books)
  - Southern part, aeromagnetic survey (E. R. King)
- Nevada (D):
  - Applied geophysics, Nevada Test Site (G. D. Bath)
  - Engineering geophysics, Nevada Test Site (R. D. Carroll)
- New Mexico, Rio Grande graben (L. E. Cordell, D)
- Pennsylvania, magnetic properties of rocks (Andrew Griscom, M)
- Puerto Rico, seismicity of Puerto Rico (A. C. Tarr, D)

Geophysics, theoretical and experimental:
- California, mass properties of oil field rocks (L. A. Beyer, M)
- Crustal studies (ARPA) (Isidore Zietz, NC)
- Earth structure studies (J. H. Healy, M)
- Earthquakes, local seismic studies (J. P. Eaton, M)
- Elastic and inelastic properties of Earth materials (Louis Peselnick, M)
- Electrical properties of rocks (R. D. Carroll, D)
- Electrical resistivity studies (A. A. R. Zohdy, D)
- Experimental rock mechanics (C. B. Raleigh, M)
- Gamma-ray spectrometry (J. A. Pitkin, D)
- Geophysical data, interpretation using electronic computers (R. G. Henderson, NC)
- Geophysical program and systems development (G. E. Andreasen, NC)
- Ground motion studies (J. H. Healy, M)
- Infrared and ultraviolet radiation studies (R. M. Moxham, NC)
- In-situ stress (R. V. de la Cruz, M)
- Interpretation of geophysical logs, Nevada Test Site (R. D. Carroll, D)
- Magnetic and luminescent properties (F. E. Senftle, NC)
- Magnetic model studies (G. E. Andreasen, NC)
- Magnetic properties laboratory (M. E. Beck, Jr., Bellingham, Wash.)
- Microwave studies (A. W. England, D)
- Paleomagnetism, Precambrian and Tertiary chronology (D. P. Elston, Flagstaff, Ariz.)
- Remanent magnetization of rocks (C. S. Grommé, M)

Geophysics, theoretical and experimental—Continued
- Resistivity interpretation (A. A. R. Zohdy, D)
- Rock behavior at high temperature and pressure (E. C. Robertson, NC)
- Seismicity patterns in time and space (C. G. Bufe, M)
- Stress studies (C. B. Raleigh, M)
- Thermodynamic properties of rocks (R. A. Robie, NC)
- Ultramafic intrusions, geophysical studies (G. A. Thompson, M)
- Volcano geophysics (E. T. Endo, M)

Geothermal investigations:
- Energy transport in ground water (A. F. Moench, w, M)
- Geochemical exploration (M. E. Hinkle, D)
- Geochemical indicators (A. H. Truesdell, M)
- Geothermal geophysics (D. R. Mabey, D)
- Geothermal hydrologic reconnaissance (F. H. Olmsted, w, M)
- Geothermal studies (A. H. Lachenbruch, M)
- Heat flow (J. H. Sass, A. H. Lachenbruch, M)
- Oxygen isotopes (J. R. O'Neil, M)
- Physics of geothermal systems (W. H. Diment, M)
- Regional volcanology (R. L. Smith, NC)
- Remote sensing (Kenneth Watson, D)
- Rio Grande geothermal (P. H. Jones, w, Bay St. Louis, Miss.)
- Rock-water interactions (R. O. Fournier, M)
- Seismic exploration (P. L. Ward, M)
- Thermal waters (D. E. White, M)
- *States:*
- Alaska, geothermal reconnaissance (T. D. Miller, M)
- Arizona, geothermal consultation (T. W. Anderson, w, Flagstaff)
- California:
  - Clear Lake-Geysers area (B. C. Hearn, Jr., NC)
  - Clear Lake-Geysers microearthquake monitoring (C. G. Bufe, M)
  - Geology of Long Valley-Mono Basin (R. A. Bailey, NC)
  - Imperial Valley geothermal (J. J. French, w, Garden Grove)
  - Imperial Valley microearthquake monitoring (D. P. Hill, M)
  - Long Valley active seismology (D. P. Hill, M)
  - Long Valley hydrology (R. E. Lewis, w, Laguna Niguel)
  - Pre-Tertiary geology of The Geysers-Clear Lake area (R. J. McLaughlin, M)
  - Seismic noise, The Geysers area (H. M. Iyer, M)
- Colorado:
  - Colorado geothermal (M. S. Bedinger, w, D)
  - Geothermal resources (G. L. Galyardt, c, D)
- Idaho (w, Boise):
  - Geothermal resources (H. W. Young)
  - Test drilling, Raft River valley (E. G. Crosthwaite)
- Nevada, geothermal reconnaissance (R. K. Hose, M)
- Oregon:
  - Geothermal reconnaissance (N. S. MacLeod, M)
  - Hydrologic reconnaissance of geothermal areas (E. A. Sammel, w, M)
- Utah, geothermal resources (J. E. Smedley, c, Salt Lake City)
- Wyoming, Yellowstone thermal areas, geology (L. J. P. Muffler, M)

Hydraulics, surface flow:
- Dispersion by turbulent flow in open channels (Nobuhiro Yotsukura, w, NC)
- Effect of temperature on winter runnoff (W. D. Simons, w, M)
- Mechanics of flow structure and fluid resistance—movable boundry (R. S. McQuivey, w, Bay St. Louis, Miss.)
- Numerical simulation of hydrodynamic phenomena by digital computer (V. C. Lai, w, NC)
- Time-of-travel studies, New York (L. A. Wagner, w, Albany)
- Unsteady flow and saline intrusions in rivers and estuaries (R. A. Baltzer, w, NC)
- *See also* Hydrologic instrumentation.

Hydrologic-data collection and processing:
- Data file for well records (R. S. McLeod, w, Madison, Wis.)
- Hydrologic probability models (W. H. Kirby, w, NC)
- Statistical inferences (E. J. Gilroy, w, NC)
- Store-retrieve hydrologic data (D. E. Vaupel, w, Mineola, N.Y.)
- *See also* Hydrologic instrumentation.

Hydrologic instrumentation:
- Analog model unit (E. P. Patten, Jr., w, NC)
- Drilling techniques (Eugene Shuter, w, D)
- Ground-water network (L. C. Dutcher, w, M)
- Hydrologic classification (L. M. Shown, w, D)
- Instrumentation and environmental studies (G. E. Ghering, w, D)
- Instrumentation research—water (H. O. Wires, w, Bay St. Louis, Miss.)
- Interagency sedimentation project (J. V. Skinner, w, Minneapolis, Minn.)
- Laboratory research, instruments, water (G. F. Smoot, w, NC)
- Lake and sea ice experiment (W. J. Campbell, w, Tacoma, Wash.)
- Remote sensing quality of water (M. C. Goldberg, w, D)
- Satellite data relay project (R. W. Paulson, w, NC)
- Satellite data relay support (D. M. Preble, w, Bay St. Louis, Miss.)
- Techniques of flood-plain mapping (G. W. Edelen, Jr., w, NC)
- *See also* Hydrologic-data collection and processing.

Hydrology, ground-water:
- Alluvial fan deposition (W. E. Price, Jr., w, NC)
- Aquifer test analysis (J. F. Daniel, w, Tuscaloosa, Ala.)
- Borehole geophysics (W. S. Keys, w, D)
- Consultation and research (C. V. Theis, w, Albuquerque, N. Mex.)
- Digital modeling ground-water flow (S. P. Larson, w, NC)
- Geothermal modeling (J. W. Mercer, w, NC)
- Ground-water staff functions (S. W. Lohman, w, D)
- Ground-water tracer studies (R. J. Sun, w, NC)
- Ground-water type curves (R. W. Stallman, w, D)
- Gulf coast hydrodynamics (P. C. Trescott, w, NC)
- Hydrologic laboratory (F. S. Riley, w, D)
- Hydrology of carbonate rocks (H. E. LeGrand, w, Raleigh, N.C.)
- Hydrology of Wilcox formation with reference to liquid waste emplacement in the Gulf Coastal Plain (P. H. Jones, w, Bay St. Louis, Miss.)
- Impact of mining on aquifers (N. J. King, w, D)

Hydrology, ground water—Continued
- Limestone hydraulic permeability (V. T. Stringfield, w, NC)
- Microbes in ground water (G. G. Ehrlich, w, M)
- Modeling of geothermal systems (M. L. Sorey, w, M)
- Recharge feasibility factors (Jacob Rubin, w, M)
- Regional ground-water studies coordination (E. M. Cushing, w, NC)
- Role of confining clays (R. G. Wolff, w, NC)
- *States:*
- Alabama, water management, Madison County (W. F. Harris, Jr., w, Huntsville)
- Arizona:
  - Ground water to Colorado River (O. J. Loeltz, w, Yuma)
  - Special site studies (H. M. Babcock, w, Tucson)
  - Water supply, Lake Mead area (R. L. Laney, w, Phoenix)
- California (w, Laguna Niguel, except as otherwise noted):
  - Barstow quality-of-water model (S. G. Robson)
  - Cahuilla Indian Reservation water resources (W. R. Moyle, Jr.)
  - Napa County ground water (J. P. Akers, w, M)
  - Water resources, Upper Coachella (L. A. Swain)
  - Water resources, Vandenberg AFB (F. W. Giessner)
- Florida:
  - Broward County (H. J. McCoy, w, Miami)
  - Deep well injection, Ft. Lauderdale (C. B. Sherwood, Jr., w, Miami)
  - Digital model, aquifer system (A. F. Robertson, w, Tampa)
  - Freshwater in saline aquifers (F. W. Meyer, w, Miami)
  - Geohydrology, citrus irrigation (W. E. Wilson III, w, Tampa)
  - Injecting wastes in saline aquifers (F. W. Meyer, w, Miami)
  - Sarasota disposal well, phase 1 (Horace Sutcliffe, Jr., w, Sarasota)
  - Storage of storm waters (G. E. Seaburn, w, Tampa)
  - Water resources, Everglades (A. L. Higer, w, Miami)
- Indiana (w, Indianapolis):
  - Dewatering effects at Bailly +1 (J. R. Marie)
  - Ground-water cost study (J. R. Marie)
  - Ground water near Carmel (D. C. Gillies)
- Iowa, hydrology of glaciated carbonate terranes (W. L. Steinhilber, w, Iowa City)
- Kansas:
  - Artificial recharge, west Kansas (J. B. Gillespie, w, Lawrence)
  - Geohydrologic maps, southwest Kansas (E. D. Gutentag, w, Garden City)
  - Arbuckle Group, southeastern Kansas (K. M. Keene, w, Lawrence)
  - Ford and Hodgeman Counties (E. C. Weakly, w, Garden City)
  - Great Bend prairie (S. W. Fader, w, Lawrence)
  - Greeley and Wichita Counties (S. E. Slagle, w, Garden City)
  - Saline water, Little Arkansas Basin (R. B. Leonard, w, Lawrence)
  - Scott and Lane Counties (E. D. Gutentag, w, Garden City)
  - Water resources, Ness County (E. D. Jenkins, w, Garden City)

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Paleozoic—Continued
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, NC)
Ordovician:
Bryozoans, Kentucky (O. L. Karklins, NC)
Stratigraphy and brachiopods, Eastern United States (R. B. Neuman, NC)
Western United States (R. J. Ross, Jr., D)
Silurian-Devonian:
Corals, northeast United States (W. A. Oliver, Jr., NC)
Upper Silurian-Lower Devonian, Eastern United States (J. M. Berdan, NC)
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Stratigraphy and brachiopods, northern Rocky Mountains and Alaska (J. T. Dutro, Jr., NC)
Stratigraphy and corals, northern Rocky Mountains (W. J. Sando, NC)
Pennsylvanian:
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Alaska (R. C. Douglass, NC)
North-central Texas (D. A. Myers, D)
Spores and pollen, Kentucky (R. M. Kosanke, D)
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Floras, Southwestern United States (S. H. Mamay, NC)
Stratigraphy and brachiopods:
Alaska (R. E. Grant, NC)
Southwestern United States (R. E. Grant, NC)
Upper Paleozoic, Western States (Mackenzie Gordon, Jr., NC)
Paleontology, vertebrate, systematic:
Artiodactyls, primitive (F. C. Whitmore, Jr., NC)
Pinnipedia (C. A. Repenning, M)
Pleistocene fauna, Big Bone Lick, Ky. (F. C. Whitmore, Jr., NC)
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Paleotectonic maps. *See* Regional studies and compilations.
Petroleum and natural gas:
Oil and gas map, North America (W. W. Mallory, D)
Organic geochemistry (J. G. Palacas, D)
Source rocks of Permian age in Utah, Idaho, Wyoming, and Montana (E. K. Maughan, D)
Western United States:
Devonian and Mississippian (C. A. Sandberg, D)
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Properties of reservoir rocks (R. F. Mast, D)
Williston basin, Wyoming, Montana, North Dakota, South Dakota (C. A. Sandberg, D)
World, petroleum-resource evaluation (A. B. Coury, D)
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Alaska (M):
Cook Inlet (L. B. Magoon III)
North Slope, petroleum geology (R. D. Carter)
California (M, except as otherwise noted):
Eastern Los Angeles basin (T. H. McCulloh, Seattle, Wash.)
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Southern San Joaquin Valley, subsurface geology (J. C. Maher)
Colorado:
Citadel Plateau (G. A. Izett, c, D)
Denver Basin, Tertiary coal zone and associated strata (P. A. Soister, c, D)
Grand Junction 2-degree quadrangle (W. B. Cashion, D)
Savery quadrangle (C. S. V. Barclay, c, D)
Montana:
Bearpaw Mountains area (B. C. Hearn, Jr., NC)
Decker quadrangle (B. E. Law, c, Casper, Wyo.)
New Mexico, San Juan basin (E. R. Landis, D)
North Dakota, White Butte 15-minute quadrangle (K. S. Soward, c, Casper)
Pennsylvania, Greater Pittsburgh region oil and gas fields (W. S. Lytle, Carnegie)
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)
Upper Valley quadrangle (W. E. Bowers, c, D)
Wyoming:
Browns Hill quadrangle (C. S. V. Barclay, c, D)
Lander area phosphate reserve (W. L. Rohrer, c, D)
Oil Mountain quadrangle (W. H. Laraway, c, Casper)
Poison Spider quadrangle (W. H. Laraway, c, Casper)
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Stratigraphy, Frontier Formation, northeastern Wyoming (E. A. Merewether, D)
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Phosphate:
Phosphoria Formation, stratigraphy and resources (R. A. Gulbrandsen, M)
Southeastern United States, phosphate resources (J. B. Cathcart, D)
States:
Alaska, Anatuvuk Pass (R. B. Sanders, c, Anchorage)
Florida, land-pebble phosphate deposits (J. B. Cathcart, D)
Idaho (c, Salt Lake City, Utah, except as otherwise noted):
Alpine quadrangle (H. F. Albee)
Palisades Dam quadrangle (D. A. Jobin, c, D)
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Montana, Melrose phosphate field (G. D. Fraser, c, D)
Nevada, Spruce Mountain 4 quadrangle (G. D. Fraser, c, D)
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Crawford Mountains (W. C. Gere, c, M)
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Wyoming:
Alpine quadrangle (H. F. Albee, c, Salt Lake City, Utah)
Bull Creek quadrangle (M. L. Schroeder, c, D)
Camp Davis quadrangle (M. L. Schroeder, c, D)
Crawford Mountains phosphate deposits (W. C. Gere, c, M)
Pickle Pass quadrangle (D. A. Jobin, c, D)
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Lakes, eastern Pennsylvania (J. L. Barker)
Water quality in Tioga River basin (J. R. Ritter)
South Carolina (w, Columbia):
Quality, Cooper River rediversion (K. F. Harris)
Savannah River plant (D. I. Cahal)
Texas, Colorado River salinity (Jack Rawson, w, Austin)
Virginia, quality of ground waters (S. M. Rogers, w, Richmond)
Washington, waste effects, coastal waters (W. L. Haushild, w, Tacoma)
Wisconsin (w, Madison):
Irrigation and ground-water quality (S. M. Hindall)
Nederlo Creek biota (P. A. Kammerer, Jr.)
Stream reaeration (R. S. Grant)
Waste assimilation in streams (R. S. Grant)
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Quicksilver. *See* Mercury.
Radioactive materials, transport in water. *See* Geochemistry, water.
Radioactive-waste disposal:
Digital model, waste transport (J. B. Robertson, w, Idaho Falls, Idaho)
Hydraulic fracturing (R. J. Sun, w, NC)
Hydrology of nuclear landfill (A. D. Randall, w, Albany, N.Y.)
Hydrology of subsurface waste disposal, National Reactor Testing Station, Idaho (J. T. Barraclough, w, Idaho Falls)
Maxey Flats investigation, Kentucky (H. H. Zehner, w, Louisville)
Radioactive waste burial (George DeBuchananne, w, NC)
Radioactive waste burial study (J. M. Cahill, w, Columbia, S.C.)
Radiohydrology technical coordination (George De-Buchananne, w, NC)
Solid radioactive waste burial sites, Tennessee (D. A. Webster)
solid-waste disposal, Los Alamos, N. Mex. (T. E. Kelly, w, Albuquerque)
Waste disposal sites (S. S. Papadopulos, w, NC)
Waste emplacement:
Preliminary overview (Harley Barnes, D)
Southeast New Mexico (A. L. Brokaw, D)
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Rare-earth metals. *See* Minor elements.
Regional studies and compilations, large areas of the United States:
Basement rock map (R. W. Bayley, M)
Paleotectonic-map folios:
Devonian System (E. G. Sable, D)
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Application of LANDSAT imagery to worldwide disaster monitoring (C. J. Robinove, l, NC)
Development of an automatic analog earthquake processor (J. P. Eaton, M)
Electromagnetic research (F. C. Frischknecht, D)
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Gamma radioactivity studies (J. A. Pitkin, D)
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Infrared surveillance of volcanoes (J. D. Friedman, D)
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LANDSAT and Skylab data for evaluation of faults and earthquake hazards (E. H. Lathram, P. M. Merifield, M)
Linear features of the conterminous U.S. (W. D. Carter, l, NC)
National aeromagnetic survey (J. R. Henderson, D)
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Satellite magnetometry (R. D. Regan, NC)
Surficial and thematic mapping (T. N. V. Karlstrom, Flagstaff, Ariz.)
Terrain mapping from Skylab data (H. W. Smedes, D)
Urban geologic studies (T. W. Offield, D)
Volcanic gas monitoring (Motoaki Sato, NC)
Application of LANDSAT data to resources inventories of small impoundments (G. A. Thorley, J. B. Reynolds, l, NC)
Comparison of land use, hydrology, and land form analysis made from LANDSAT imagery and from aerial orthophotographs (G. A. Thorley, A. M. Woll, l, NC)
LANDSAT data for surface-water estimates (Morris Deutsch, D. G. Moore, l, NC)
LANDSAT-1 experiments:
Analysis of multispectral data, Pakistan (R. G. Schmidt, NC)
CARETS—A prototype regional environmental information system (R. H. Alexander, l, NC)
Census cities experiment in urban-change detection (J. R. Wray, l, NC)
Computer mapping of terrain using multispectral data, Yellowstone National Park (H. W. Smedes, D)
Effects of the atmosphere on multispectral mapping of rock type by computer, Cripple Creek-Canon City, Colo. (H. W. Smedes, D)
Evaluation of Great Plains area (R. B. Morrison, D)
Evaluation of Iranian playas, potential locations for economic and engineering development (D. B. Krinsley, NC)
Geologic mapping, South America (W. D. Carter, l, NC)
Identification of geostructures, mineral resource evaluation (George Gryc, M)
Investigations of the Basin and Range-Colorado Plateau boundary, Arizona (D. P. Elston, Ivo Lucchitta, Flagstaff)
Iron-absorption band analysis for the discrimination of iron-rich zones (L. C. Rowan, NC)

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- Geologic applications—Continued
  - LANDSAT-1 experiments—Continued
    - Land-use mapping and modeling for the Phoenix quadrangle (J. L. Place, l, NC)
    - Monitoring changing geologic features, Texas Gulf Coast (R. B. Hunter, Corpus Christi, Tex.)
    - Morphology, provenance, and movement of desert sand seas in Africa, Asia, and Australia (E. D. McKee, D)
    - North-central Arizona Test Site (D. P. Elston, Flagstaff)
    - Post-1890 A.D. episode erosion, Arizona Regional Ecological Test Site (R. B. Morrison, D)
    - Prototype volcano surveillance network (J. P. Eaton, M)
    - Remote sensing of permafrost and geologic hazards in Alaska (O. J. Ferrians, Jr., M)
    - Structural, volcanic, glaciologic, and vegetation mapping, Iceland (R. S. Williams, Jr., l, NC)
    - Studies of the inner shelf and coastal sedimentation environment of the Beaufort Sea (E. Reimnitz, M)
    - Study of multispectral imagery, Northwestern Saudi Arabia (A. J. Bodenlos, NC)
    - Suspended particulate matter in nearshore surface waters, Northeast Pacific Ocean and the Hawaiian Islands (P. R. Carlson, M)
    - Thermal surveillance of active volcanoes (J. D. Friedman, NC)
  - LANDSAT-2 experiments, mineral resource inventory and exploration, Andes Mountains (W. D. Carter, l, NC)
  - LANDSAT imagery and DCS to relate water depth to observed area of inundation of coastal marshes (G. A. Thorley, W. Herke, l, NC)
  - Monitoring weather parameters for the High Plains Cooperative Program with LANDSAT DCS (G. A. Thorley, A. M. Kahn, l, NC)
  - Northern Great Plains wetlands from LANDSAT data (Morris Deutsch, G. Moore, l, NC)
  - Skylab/EREP studies:
    - Effects of the atmosphere on multispectral mapping of rock type by computer, Cripple Creek-Canon City, Colo. (H. W. Smedes, D)
    - Evaluation of Great Plains area (R. B. Morrison, D)
    - Marine and coastal processes on the Puerto Rico-Virgin Islands Platform (J. V. A. Trumbull, Corpus Christi, Tex.)
    - Multispectral mapping of terrain by computer, Yellowstone National Park (H. W. Smedes, D)
    - Post-1890 A.D. episode erosion, Arizona Regional Ecological Test Site (R. B. Morrison, D)
    - Remote sensing geophysics (Kenneth Watson, D)
    - Urban and regional land-use analysis—CARETS and census cities experiment (R. H. Alexander, l, NC)
  - Skylab/visual observations:
    - Desert sand seas (E. D. McKee, D; C. S. Breed, Flagstaff, Ariz.)
    - Volcanologic features (J. D. Friedman, D)
  - Time-lapse satellite data for monitoring dynamic hydrologic phenomena (Morris Deutsch, S. Serebreny, l, NC)

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- Hydrologic applications:
  - Application of aerial-measurement techniques (M. L. Brown, w, Prescott, Ariz.)
  - Arctic Ice Dynamics Joint Experiment (H. E. Skibitzke, w, Prescott, Ariz.)
  - Arizona Test Site (H. H. Schumann, w, Phoenix)
  - Basin precipitation from satellite data (Morris Deutsch, P. A. Davis, l, NC)
  - Delaware River basin LANDSAT project (R. W. Paulson, w, Harrisburg, Pa.)
  - Delineation of shallow glacial drift aquifers in eastern South Dakota (Morris Deutsch, P. Rahn, l, NC)
  - Development of aerial-measurement techniques (H. E. Skibitzke, Prescott, Ariz.)
  - Detection of oil on marine waters using LANDSAT data (Morris Deutsch, l, NC)
  - Image-map atlas of the Lake Ontario basin (Morris Deutsch, A. Falconer, l, NC)
  - LANDSAT snowcover mapping (M. F. Meier, w, Tacoma, Wash.)
  - LANDSAT—South Florida (A. L. Higer, w, Miami, Fla.)
  - LANDSAT data for ground-water exploration (Morris Deutsch, l, NC)
  - Measurement of areal and temporal differences in surface-water conditions in migratory bird habitat (G. A. Thorley, D. S. Gilmer, l, NC)
  - Microwave remote sensing (G. K. Moore, w, Bay St. Louis, Miss.)
  - Monitoring center pivot irrigation, Holt County, Nebraska (W. R. Hemphill, l, NC)
  - Optical enhancement of LANDSAT imagery for hydrogeological appraisal, north Yemen (Morris Deutsch, l, NC)
  - Polar-ice remote sensing (W. J. Campbell, w, Tacoma, Wash.)
  - Remote sensing of Elephant Butte-Fort Quitman Project (G. A. Thorley, D. Mach, l, NC)
  - Remote-sensing techniques (E. J. Pluhowski, w, NC)
  - Remote sensing, wetlands (V. P. Carter, w, NC)
  - Snowpack measurements by radar (M. F. Meier, w, Tacoma, Wash.)
  - Usefulness of remote sensing imagery to the Wild and Scenic Rivers Act (G. A. Thorley, R. N. Colwell, l, NC)
  - *States:*
  - Alabama, remote-sensing data collection (J. G. Newton, w, Tuscaloosa)
  - Arizona, snowcover mapping (H. H. Schumann, w, Phoenix)
  - Connecticut, Connecticut River estuary (F. H. Ruggles, Jr., w, Hartford)
  - Minnesota, remote sensing for water management (G. F. Lindholm, w, St. Paul)
  - South Carolina, sediment sources and loading (S. J. Playton, w, Columbia)
  - Land resources applications:
    - Applications of LANDSAT imagery to land systems mapping, Australia (C. J. Robinove, l, NC)
  - Colorado River natural resources and land-use data acquisition (G. A. Thorley, R. L. Hansen, l, NC)

Uranium—Continued
States—Continued
Wyoming—Continued
Crooks Peak quadrangle (L. J. Schmitt, Jr.)
Granite as a source rock of uranium (J. S. Stuckless, D)
Northeastern Great Divide Basin (L. J. Schmitt, Jr.)
Powder River Basin (E. S. Santos)
Sagebrush Park quadrangle (L. J. Schmitt, Jr.)
Stratigraphic analysis of western interior Cretaceous uranium basins (H. W. Dodge, Jr.)
Urban geology:
States:
Alaska (D):
Anchorage area (Ernest Dobrovolny)
Juneau area (R. D. Miller)
Sitka area (L. A. Yehle)
Small coastal communities (R. W. Lemke)
Arizona, Phoenix-Tucson region resources (T. G. Theodore, M)
California (M):
Coastal geologic processes (K. R. Lajoie)
Earth science planning applications (W. J. Kockelman)
Flatlands materials and their land-use significance (E. J. Helley)
Geologic factors in open space (R. M. Gulliver)
Hillside materials and their land-use significance (C. M. Wentworth, Jr.)
Malibu Beach and Topanga quadrangles (R. F. Yerkes)
Palo Alto, San Mateo, and Montara Mountain quadrangles (E. H. Pampeyan)
Point Dume and Triunfo Pass quadrangles (R. H. Campbell)
Regional slope stability (T. H. Nilsen)
San Francisco Bay region, environment and resources planning study:
Bedrock geology (M. C. Blake)
Marine geology (D. S. McCulloch)
Open space (C. S. Danielson)
San Andreas fault—basement studies (D. C. Ross)
San Andreas fault—basin studies (J. A. Bartow)
San Andreas fault—regional framework (E. E. Brabb)
San Andreas fault—tectonic framework (R. D. Brown)
San Mateo County cooperative (H. D. Gower)
Sargent-Berrocal fault zone (R. J. McLaughlin, (D. H. Sorg)
Sediments, engineering-geology studies (D. R. Nichols, Julius Schlocker)
Seismicity and ground motion (W. B. Joyner)
Colorado (D):
Denver-Front Range urban corridor, remote sensing (T. W. Offield)
Denver metropolitan area (R. M. Lindvall)
Denver mountain soils (regolith), Front Range urban corridor (K. L. Pierce, P. W. Schmidt)
Denver urban area, regional geochemistry (H. A. Tourtelot)
Denver urban area study:
Geologic map, Boulder-Ft. Collins-Greeley area (R. B. Colton)
Geologic map, greater Denver area (D. E. Trimble)

Urban geology—Continued
States—Continued
Colorado—Continued
Denver urban area study—Continued
Geologic map, Colorado Springs-Castle Rock area (W. R. Hansen)
Land-use classification, Colorado Front Range urban corridor (W. R. Hansen, L. B. Driscoll, D)
Engineering geology mapping research, Denver region (H. E. Simpson)
Terrain mapping from Skylab data (H. W. Smedes)
Connecticut (Middletown):
Connecticut Valley urban area study:
Distribution of clay deposits (Fred Pessl, Jr.)
Depth to bedrock (Fred Pessl, Jr.)
Maryland, Baltimore-Washington urban area study (J. T. Hack, NC)
Massachusetts, Boston and vicinity (C. A. Kaye, Boston)
Montana, geology for planning, Helena region (R. G. Schmidt, NC)
New Mexico, geology of urban development (H. E. Malde, D)
Pennsylvania:
Areas of subsidence due to coal mining (K. O. Bushnell, Slippery Rock)
Coal mining features, Allegheny County (W. E. Davies, NC)
Disturbed ground, Allegheny County (R. P. Briggs, Carnegie)
Greater Pittsburgh regional studies (R. P. Briggs, Carnegie)
Landslides, Allegheny County (R. P. Briggs, Carnegie)
Land use affected by landsliding (R. P. Briggs, Carnegie)
Limitations of land, Allegheny County (R. P. Briggs, Carnegie)
Pittsburgh coal bed outcrop (K. O. Bushnell, Slippery Rock)
Rock types, Allegheny County (W. R. Kohl, Pittsburgh)
Susceptibility to landsliding, Allegheny County (J. S. Pomeroy, NC)
Upper Freeport coal bed outcrop (K. O. Bushnell, Slippery Rock)
South Dakota, Rapid City area (J. M. Cattermole, D)
Utah, Salt Lake City and vicinity (Richard Van Horn, D)
Virginia, geohydrologic mapping of Fairfax County (A. J. Froelich, NC)
Urban hydrology:
Geohydrology, urban planning (J. R. Ward, w, Lawrence, Kans.)
Hydrogeologic regime in land-use planning (Seymour Subitzky, w, Trenton, N.J.)
Hydrogeology of landfills (H. H. Zehner, w, Louisville, Ky.)
Investigation of urban hydrologic parameters (W. J. Schneider, w, NC)
RALI southern Florida (T. J. Buchanan, w, Miami, Fla.)
Studies for tunnel construction (E. M. Cushing, w, NC)
Urban areas reconnaissance (W. E. Hale, w, Albuquerque, N. Mex.)
Urban sedimentology (H. P. Guy, w, NC)

Water resources—Continued
- Chattahoochee intensive river quality (R. N. Cherry, w, Atlanta, Ga.)
- Columbia-North Pacific ground water (B. L. Foxworthy, w, Tacoma, Wash.)
- Comprehensive studies, Pacific Northwest (L. E. Newcomb, w, M)
- Dams, weirs, and flumes (H. J. Tracy, w, Atlanta, Ga.)
- Data coordination, acquisition and storage:
  - NAWDEX Project (S. M. Lang, w, NC)
  - Systems Analysis Laboratory (N. C. Matalas, w, NC)
  - Water Data Coordination (R. H. Langford, w, NC)
- East Triassic waste-disposal study (G. L. Bain, w, Raleigh, N.C.)
- Environmental impact analyses support (W. J. Schneider, w, NC)
- Evaluation of land treatment (R. F. Hadley, w, D)
- Foreign countries:
- Canada:
  - Gasline environmental impact statement (D. M. Culbertson, w, M)
  - Gas pipeline (V. K. Berwick, w, Anchorage, Alaska)
  - Brazil, surface water, national program (D. C. Perkins, w, Rio de Janeiro)
  - India, ground-water investigations in states of Madhya Pradesh, Gujarat, Maharashtra and Mysore (J. R. Jones, w, NC)
- Kenya (w, Nairobi):
  - Hydrogeology of eastern Kenya (W. V. Swarzenski)
  - Range water resources (N. E. McClymonds)
  - Nepal, hydrogeology off Terai region (G. C. Tibbitts, Jr., w, Katmandu)
- Yemen, water and mineral survey, north Yemen (J. R. Jones, w, Ṣan'ā')
- General hydrologic research (R. L. Nace, w, Raleigh, N.C.)
- Ground-water appraisal, middle Atlantic region (Allen Sinnott, w, Trenton, N.J.)
- Ground-water appraisal, New England region (Allen Sinnott, w, Trenton, N.J.)
- Ground water, Missouri Basin (O. J. Taylor, w, D)
- Ground-water, Southeastern States (D. J. Cederstrom, w, NC)
- Intensive river quality assessment (D. A. Rickert, w, Portland, Oreg.)
- Intermediate-depth drilling (L. C. Dutcher, w, M)
- Madison Limestone plan of study (E. M. Cushing, w, D)
- National assessment (S. M. Lang, w, NC)
- Northeast drought (M. T. Thomson, w, NC)
- Northeastern Region field coordination (J. W. Geurin, w, NC)
- Northwest water-resources data center (N. A. Kallio, w, Portland, Oreg.)
- Off-the-road vehicle use (C. T. Snyder, w, M)
- Pilot study, greater Pittsburgh (R. M. Beall, w, Pittsburgh, Pa.)
- Powell arid lands centennial (R. F. Hadley, w, D)
- Quality-of-water accounting network (R. J. Pickering, w, NC)
- Rating extensions (K. L. Wahl, w, NC)
- Rehabilitation potential, energy lands (L. M. Shown, w, D)
- Reservoir bank storage study (T. H. Thompson, w, M)

Water resources—Continued
- Southeastern Region field coordination (M. D. Hale, w, Atlanta, Ga.)
- Subsurface waste emplacement potential (P. M. Brown, w, Raleigh, N.C.)
- Water-resources activities (J. R. Carter, w, D)
- Water-supplies from Madison Limestone (F. A. Swenson, w, D)
- Water-supply exploration (N. J. King, w, D)
- Waterway treaty engineering studies (J. A. Bettendorf, w, NC)
- Western Region field coordination (G. L. Bodhaine, w, M)
- *States and territories:*
- Alabama (w, Montgomery, except as noted otherwise):
  - Cretaceous aquifer simulation (R. A. Gardner)
  - Drainage areas (C. O. Ming)
  - Geology and hydrology along highway locations and rest areas (J. C. Scott)
  - Hydraulics of bridge design (J. W. Board)
  - Low flows of Alabama streams (W. J. Powell, E. C. Hayes, w, Tuscaloosa)
  - Plans, reports, and information (W. J. Powell, w, Tuscaloosa)
  - Tennessee River basin (J. R. Harkins, w, Tuscaloosa)
- Alaska (w, Anchorage, except as noted otherwise):
  - Alaskan gas pipeline environmental impact statement (A. J. Feulner)
  - Arctic resources (J. M. Childers)
  - Coal resources study (A. J. Feulner)
  - Cordova water resources (G. S. Anderson)
  - Hydrology:
    - Anchorage area (G. O. Balding)
    - Greater Juneau Borough (J. A. McConaghy, Juneau)
    - Hydrologic environment of the trans-Alaska pipeline system (TAPS) (J. M. Childers)
    - Hydrologic planning, resource team (A. J. Feulner)
    - Hydrologic studies for Alaskan Air Command (R. J. Madison)
    - Kenai Peninsula Borough (G. S. Anderson)
  - Municipal water supply (D. A. Morris)
  - Surface water, Valdez-Copper Center project (C. E. Sloan)
- American Samoa, surface-water resources (Iwao Matsuoka, w, Honolulu, Haw.)
- Arizona:
  - Black Mesa hydrologic study (R. M. Myrick, w, Tucson)
  - Black Mesa monitoring program (G. W. Levings, w, Flagstaff)
  - Channel loss study (T. W. Anderson, w, Phoenix)
  - Coconino Sandstone water budget, Navajo County (L. J. Mann, w, Flagstaff)
  - Copper Basin study (B. W. Thomsen, w, Phoenix)
  - Ground-water appraisal, Lower Colorado River (E. S. Davidson, w, Tucson)
  - National eutrophication survey (E. B. Hodges, w, Tucson)
  - Sedona ground-water availability (G. W. Levings, w, Flagstaff)
- Arkansas (w, Little Rock):
  - Bayou Bartholomew systems study (M. E. Broom)
  - Cache River aquifer-stream system (M. E. Broom)
  - Characteristics of streams (M. S. Hines)

Water resources—Continued
- *States and territories—Continued*
  - Arkansas (w, Little Rock)—Continued
    - Ground-water appraisal, AWRRB (M. S. Bedinger)
    - Investigations and hydrologic information (R. T. Sniegocki)
    - National eutrophication survey (M. S. Hines)
    - Red River navigation study (A. H. Ludwig)
    - Time-of-travel study (T. E. Lamb)
    - Urban effects on Hot Springs (M. S. Bedinger)
  - California (w, M, except as noted otherwise):
    - Antelope Valley ground-water model (S. G. Robson, w, Laguna Niguel)
    - Ground water:
      - Antelope Valley area (F. W. Geissner, w, Laguna Niguel)
      - City of Modesto, ground-water planning (R. W. Page, Sacramento)
      - Clovis (R. W. Page, w, Sacramento)
      - Death Valley National Monument hydrologic reconnaissance (G. A. Miller, w, Laguna Niguel)
      - Geohydrology of Garner Valley (T. J. Durbin, w, Laguna Niguel)
      - Geohydrology, Round Valley (K. S. Muir)
      - Indian Wells Valley (J. H. Koehler, w, Laguna Niguel)
      - Joshua Tree (G. A. Miller, w, Laguna Niguel)
      - Madera area, ground-water model (W. D. Nichols, w, Sacramento)
      - Redlands nitrate study (L. A. Eccles, w, Laguna Niguel)
      - Sacramento Valley (R. M. Bloyd, Jr., w, Sacramento)
      - Santa Barbara-San Luis Obispo (G. A. Miller, w, Laguna Niguel)
      - Santa Cruz (K. S. Muir)
      - South California (W. R. Moyle, Jr., w, Laguna Niguel)
      - Withdrawals, statewide (H. T. Mitten, w, Sacramento)
    - Indian reservations (J. W. Wark)
    - Quality of water:
      - Ground-water quality, Suisun Bay (Chabot Kilburn)
      - Highway erosion, Tahoe basin (C. G. Kroll, w, Tahoe City)
      - Lakes and reservoirs (R. C. Averett)
      - Trace metals control, Sacramento (R. F. Ferreira, w, Sacramento)
    - Surface water:
      - Floods—small drainage areas (A. O. Waananen)
      - National eutrophication survey (J. R. Crippen)
      - Sediment, Redwoods National Park (J. M. Knott)
      - Urbanization, Santa Clara County (J. M. Knott)
  - Colorado (w, D, except as noted otherwise):
    - Coal rehabilitation (W. E. Hofstra)
    - Evaporation, Colorado lakes (D. B. Adams)
    - Ground water:
      - Aquifer testing (J. B. Weeks)
      - Geophysical logging (J. B. Weeks)
      - High Plains of Colorado (W. E. Hofstra)
      - Near Lake Minnequa (O. J. Taylor, w, Pueblo)
      - Potentiometric surface mapping (J. B. Weeks)
      - Recharge, Bijou Creek (W. E. Hofstra)
      - Southern Ute lands (E. R. Hampton)

Water resources—Continued
- *States and territories—Continued*
  - Colorado (w, D, except as noted otherwise)—Continued
    - Ground water—Continued
      - Southwestern Colorado (E. R. Hampton)
      - U.S. Bureau of Mines prototype mine (J. B. Weeks)
    - Hydrology:
      - Arkansas River basin (O. J. Taylor, w, Pueblo)
      - El Paso County (D. L. Bingham)
      - Parachute-Roan Creek Basin (G. H. Leavesley)
      - Rocky Flats (R. T. Hurr)
      - San Luis Valley (O. J. Taylor, w, Pueblo)
      - South Platte River basin, Henderson to State line (R. T. Hurr)
    - National eutrophication survey (H. E. Petsch, Jr.)
    - National Parks (J. E. Biesecker)
    - Quality of water:
      - Geochemical investigation (S. G. Robson)
      - Hydrology of Jefferson County (W. E. Hofstra)
      - Sediment yield, Piceance Basin (V. W. Norman)
      - Water-quality monitor network (J. E. Biesecker)
      - Water resources, Boxelder alluvium (R. T. Hurr)
      - West slope aquifers (E. R. Hampton)
    - Spring hydraulics (J. B. Weeks)
    - Water resources, Park-Teller County (O. J. Taylor, w, Pueblo)
  - Connecticut (w, Hartford):
    - Hydrogeology, south-central Connecticut (R. L. Melvin)
    - Hydrology of Canaan hydro site (F. H. Ruggles, Jr.)
    - Part 7, Upper Connecticut River basin (R. B. Ryder)
    - Part 8, Quinnipiac River basin (D. L. Mazzaferro)
    - Part 9, Farmington River basin (H. T. Hopkins)
    - Part 10, lower Connecticut River basin (L. A. Weiss)
    - Short-term studies (F. H. Ruggles, Jr.)
  - Delaware, aquifer-model studies (R. H. Johnston, w, Dover)
  - Florida (w, Tallahassee, except as noted otherwise):
    - Bridge-site studies (W. C. Bridges)
    - Broward County (C. B. Sherwood, w, Miami)
    - Digital model, Palm Beach County (L. F. Land, w, Miami)
    - Ground water:
      - Aquifer mapping, south Florida (K. E. Vanlier, w, Miami)
      - Artificial recharge, west-central Florida (W. C. Sinclair, w, Tampa)
      - Coastal springs (W. C. Sinclair, w, Miami)
      - Fort Lauderdale area, special studies (H. J. McCoy, w, Miami)
      - Hallandale area, (H. W. Bearden, w, Miami)
      - Hollywood area (H. W. Bearden, w, Miami)
      - Hydrogeology, middle Peace basin (W. E. Wilson III, w, Tampa)
      - Hydrology, Cocoa well field (J. B. Holly, w, Winter Park)
      - Hydrology, Manatee County (Horace Sutcliffe, Jr., w, Sarasota)
      - Hydrology, Sarasota County (Horace Sutcliffe, Jr., w, Sarasota)
      - North Brevard County aquifer study (H. F. Grubb, w, Winter Park)

Water resources—Continued
States and territories—Continued
Florida (w, Tallahassee, except as noted otherwise)—Continued
Ground water—Continued
Ochlockonee River basin investigation (C. A. Pascale)
Oklawaha shallow aquifer study (Warren Anderson, w, Winter Park)
Palm Beach County flatlands (K. E. Vanlier, w, Miami)
Peace and Alafia River basins (A. F. Robertson, w, Tampa)
Potentiometric St. Petersburg-Tampa (C. B. Hutchinson, w, Tampa)
Recharge, Orange County (P. W. Bush, w, Winter Park)
Salt-water intrusion, Fernandina (R. W. Fairchild, w, Jacksonville)
Sand-gravel aquifer, Pensacola (Henry Trapp)
Santa Fe River basin (J. C. Rosenau)
Sewage effluent disposal, irrigation (L. J. Slack)
Shallow aquifer, Brevard County (J. M. Frazee, Jr., w, Winter Park)
Shallow aquifers, Alafia and Peace (J. D. Hunn, w, Tampa)
Southwestern Hillsborough County (J. W. Stewart, w, Tampa)
Springs of Florida (J. C. Rosenau, w, Ocala)
Technical assistance, Hillsborough County (J. W. Stewart, w, Tampa)
Technical assistance, south Florida (Howard Klein, w, Miami)
Urban hydrology, Englewood area (H. Sutcliffe, Jr., w, Sarasota)
Verna well field (Horace Sutcliffe, Jr., w, Sarasota)
Water resources, Duval-Nassau (G. W. Leve, w, Jacksonville)
Water resources, Martin County (H. G. Rodis, w, Miami)
Water resources, Tequesta (L. F. Land, w, Miami)
Water-supply potential, Green Swamp (H. F. Grubb, w, Winter Park)
Hydrogeologic maps, Seminole County (W. D. Wood, w, Winter Park)
Hydrologic suitability study (L. V. Causey, w, Jacksonville)
Hydrology of lakes (G. H. Hughes)
Hydrology, Volusia County (P. W. Bush, w, Winter Park)
Lake recharge investigations (Warren Anderson, w, Winter Park)
Lee County (D. H. Boggess, w, Ft. Myers)
Mapping, Green Swamp (B. F. McPherson, w, Miami)
Marion County flood studies (Warren Anderson, w, Ocala)
Osceola County (J. M. Frazee, w, Winter Park)
Palm Beach County (H. G. Rodis, w, Miami)
Quality of water:
Chemistry of Florida streams (D. A. Goolsby)
Estuarine hydrology, Tampa Bay (C. R. Goodwin, w, Tampa)
Landfill and water quality (J. E. Hull, w, Miami)
Solid waste, Hillsborough County (Mario Fernandez, Jr., w, Tampa)

Water resources—Continued
States and territories—Continued
Florida (w, Tallahassee, except as noted otherwise)—Continued
Quality of water—Continued
Solid waste, St. Petersburg (Mario Fernandez, Jr., w, Tampa)
Subsurface disposal, Pinellas (J. J. Hickey, w, Tampa)
Technical assistance, Department of Pollution Control (D. A. Goolsby)
Water supply, Temple Terrace (J. W. Stewart, w, Tampa)
Riviera Beach investigations (L. F. Land, w, Miami)
Seminole County (C. H. Tibbals, w, Winter Park)
Special studies, statewide (C. S. Conover)
Surface water:
Drawdown of Lake Carlton (Warren Anderson, w, Winter Park)
Hydrology study, Fakahatchee Strand (L. J. Swayze, w, Miami)
Lakes in southwest Florida (J. D. Hunn, w, Tampa)
Manasota planning report (Horace Sutcliffe, Jr., w, Sarasota)
Manasota technical assistance (Horace Sutcliffe, Jr., w, Sarasota)
Technical assistance:
Northwest Florida Water Management District (J. C. Rosenau)
St. Johns River (G. W. Leve, w, Jacksonville)
Suwannee River Water Management District (J. C. Rosenau)
Technical support, ground water (A. F. Robertson, w, Tampa)
Tri-county investigation (C. B. Bentley, w, Jacksonville)
Waccasassa Basin hydrology (G. F. Taylor, w, Winter Park)
Water atlas (S. D. Leach)
Water resources, Hendry County (T. M. Missimer, w, Miami)
Water resources of Orange County (C. H. Tibbals, w, Winter Park)
Western Collier County (H. J. McCoy, w, Miami)
Georgia (w, Doraville, except as noted otherwise):
Cretaceous (R. C. Vorhis)
Information system (J. R. George)
National eutrophication survey (R. F. Carter)
Northwest Georgia geology and water (C. W. Cressler, w, Calhoun)
Valdosta hydrology (R. E. Krause)
Hawaii (w, Honolulu):
Data management, Guam (C. J. Huxel, Jr.)
Ground water in Waialua, Oahu (R. H. Dale)
Kauai water resources survey (R. J. Burt)
Regional study (B. L. Jones)
Topical studies (F. T. Hidaka)
Idaho (w, Boise):
Flow in Silver Creek, Idaho (J. A. Moreland)
Hydrologic environment, White Clouds area (W. W. Emmett)
Kootenai Board—WWT (H. K. Hall)
National eutrophication survey (H. A. Ray)

Water resources—Continued

States and territories—Continued

- Mississippi (w, Jackson)—Continued
  - Water use (J. A. Callahan)
- Missouri (w, Rolla):
  - Ground-water resources - Springfield area (L. F. Emmett)
  - National eutrophication survey (John Skelton)
  - Small lakes in Missouri (J. H. Barks)
  - Water quality, scenic riverways (J. H. Barks)
- Montana (w, Helena, except as noted otherwise):
  - Ground water:
    - Central Powder River valley (W. R. Miller, w, Billings)
    - Clark Fork basin (A. J. Boettcher)
    - Fort Belknap (R. D. Feltis)
    - Fort Union Formation (W. B. Hopkins, w, Billings)
    - Hydrology, lower flathead (A. J. Boettcher)
    - Madison Group (W. R. Miller, w, Billings)
    - Mined lands reclamation (W. R. Hotchkiss)
    - Northern Judith basin (R. D. Feltis, w, Billings)
    - Quality of water near Libby (A. J. Boettcher)
    - "Saline seeps" (R. G. McMurtrey)
    - Southern Powder River valley (W. R. Miller)
    - Special investigations (D. L. Coffin)
    - Water availability, Madison (W. R. Miller, w, Billings)
    - Water supplies for national parks, monuments, and recreation areas (D. L. Coffin)
  - Mining effects, shallow water (R. S. Roberts)
  - National eutrophication survey (R. R. Shields)
- Nebraska (w, Lincoln):
  - Assessment of ground-water quality (L. R. Petri)
  - Ground-water resources of Boyd County (V. L. Souders)
  - Ground-water use, Blue River basin (E. K. Steele, Jr.)
  - Hydrogeology of southwest Nebraska (E. G. Lappala)
  - Movement of nitrogen into aquifers (L. R. Petri)
  - National eutrophication survey (G. G. Jamison)
  - Seward County (M. J. Ellis)
  - Time-of-travel data (L. R. Petri)
  - Water in the Loup River basin (R. Bentall)
- Nevada (w, Carson City):
  - Aquifers in the Fallon area (P. A. Glancy)
  - National eutrophication survey (D. O. Moore)
  - Smith Valley (F. E. Rush)
  - Statewide reconnaissance (F. E. Rush)
  - Topical studies (J. P. Monis)
  - Water supply, Cold Spring Valley (A. S. Van Denburgh)
  - Water supply, mining districts (H. A. Shamberger)
- New Hampshire, ground-water reconnaissance, river basins (J. E. Cotton, w, Concord)
- New Jersey (w, Trenton):
  - Automatic processing of ground-water data (William Kam)
  - Base-flow studies (E. G. Miller)
  - Camden County, geology and ground-water resources (G. M. Farlekas)
  - Miscellaneous Federal work (Harold Meisler)
  - Nitrification in southern New Jersey (J. C. Schornick, Jr.)
  - Problem river studies (J. C. Schornick, Jr.)
  - Quantification non-point pollution (J. C. Schornick, Jr.)
  - Short-term studies (Harold Meisler)
  - Test drill geophysical logging (J. E. Luzier)
  - Time-of-travel study (E. A. Pustay)

Water resources—Continued

States and territories—Continued

- New Jersey (w, Trenton)—Continued
  - Water resources, Wharton Trace (William Kam)
  - Water temperatures (M. G. McDonald)
- New Mexico (w, Albuquerque):
  - Bureau of Indian Affairs water-supply investigations (F. P. Lyford)
  - Cimarron Basin analysis (P. L. Soule)
  - Coal-lease areas, northwest New Mexico (Kim Ong)
  - Ground water:
    - Capitan Reef (W. L. Hiss)
    - Gallup ground-water exploration (W. L. Hiss)
    - Harding County (F. D. Trauger)
    - Miscellaneous activities, State Engineer (J. B. Cooper)
    - White Sands Missile Range, water levels and pumpage (H. D. Hudson)
  - Surface water:
    - National eutrophication survey (L. P. Denis)
    - Pojoaque River analyses (L. J. Reiland)
  - New Mexico data bank (P. L. Soule)
  - Rio Grande Commission (P. L. Soule)
- New York (w, Albany, except as noted otherwise):
  - Basin recharge with sewage effluent (R. C. Prill, w, Mineola)
  - Column-basin studies (M. S. Garber, w, Mineola)
  - Deep-well waste disposal in western New York (R. M. Waller)
  - Delaware basin water-quality study (G. E. Williams)
  - Hydrogeology of southeast Nassau County (H. F. H. Ku, w, Mineola)
  - Hydrologic modeling (R. T. Getzen, w, Mineoloa)
  - Long Island recharge (R. C. Prill, w, Mineola)
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